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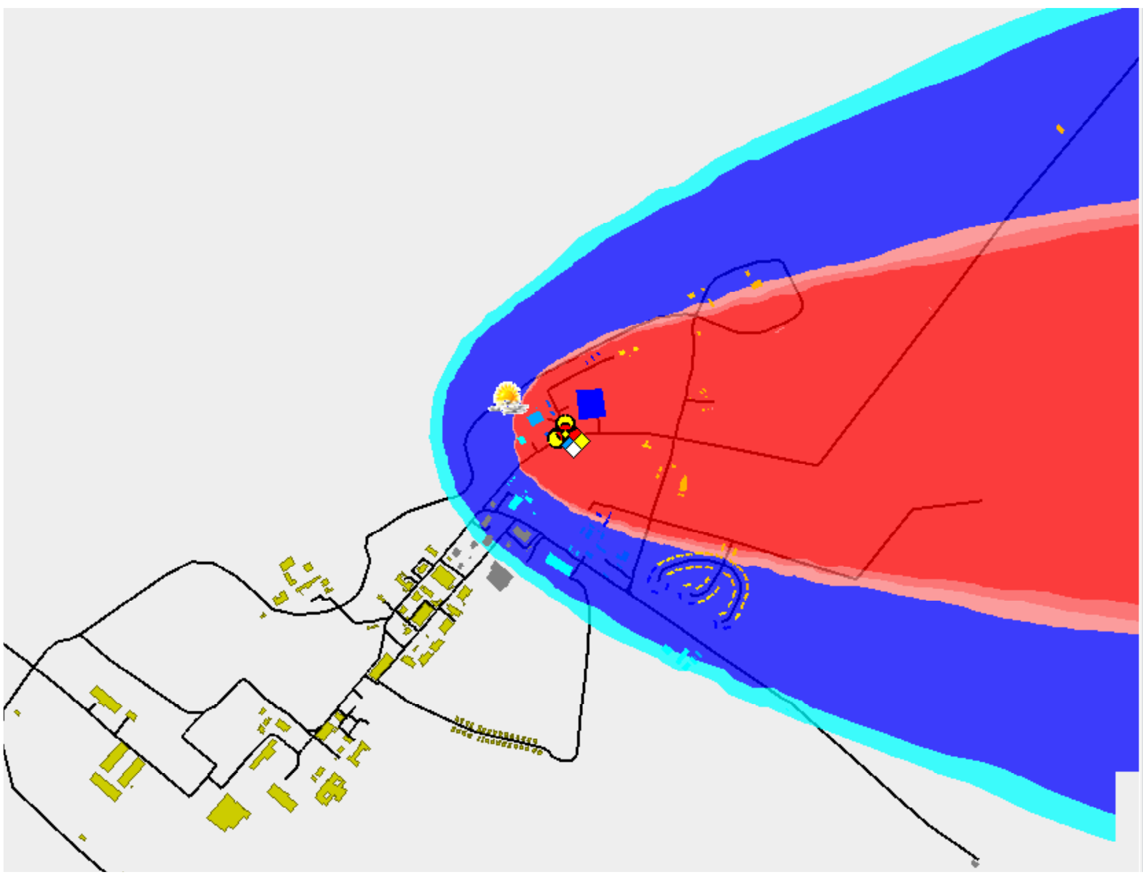
Installation Technology Transfer Program

Demonstration of CBR Modeling and Simulation Tool (CBRSim) Capabilities

Kathy L. Simunich, Timothy K. Perkins, David M. Bailey, David Brown, and Pamela Sydelko

April 2009



Construction Engineering Research Laboratory

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Demonstration of CBR Modeling and Simulation Tool (CBRSim) Capabilities

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Final report

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Abstract: The release of an airborne hazardous substance nearby or within a military facility can threaten the life or safety of government personnel and the general public. Vulnerability assessments using simulants and sensors are expensive and may interfere with normal facility operations. Simulation modeling technology offers a possible method for understanding how airborne hazardous substances may circulate inside and around any specific facility affected by an attack or accidental release. Improved understanding of airborne threats could shorten emergency response time and minimize casualties at the site. A computerized simulation tool called CBRSim, developed under an earlier U.S. Army research program, provides an environment for creating and testing models of release patterns for airborne weaponized agents within or nearby a targeted facility. This report describes the CBRSim tool and explains how it could be used to assess chemical, biological, and radiological (CBR) weapons effects for specific facilities. The discussion includes the results of case studies and simulations run during a workshop for military installation stakeholders presented at Fort Carson, CO.

Demonstration results indicate that CBRSim is not sufficiently developed to provide reliable situation data in real time, but offers benefits as a training and education aid for facility managers and first responders.

Table of Contents

List of Figures

Preface

This study was conducted for the Assistant Chief of Staff for Installation Management (ACSIM) under the U.S. Army Installation Technology Transfer Program (ITTP); Project 150309, Activity A1110 and A1110E, "Chemical Biological and Radiological (CBR) Protection – Airborne." The ITTP Program Manager was Kelly M. Dilks.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Vicki L. Van Blaricum was Chief, CEERD-CF-M; L. Michael Golish was Chief, CEERD-CF; and Martin J. Savoie was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Gary E. Johnston was the Commander and Executive Director of ERDC, and Dr. James R. Houston was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters

1 Introduction

1.1 Background

Annual vulnerability assessments and realistic force protection exercises, including emergency response planning, are required by Department of Defense (DoD) policy. The military services and installation commanders are required by Department of Defense Directive(DoDD) 2000.12 and Department of Defense Instruction (DoDI) 2000.16, standard 26, to conduct a higher headquarters vulnerability assessment of their installation’s anti-terrorism (AT) programs.

A terrorist’s release of a chemical, biological, or radiological (CBR) agent can infiltrate heating, ventilation and air conditioning (HVAC) systems, and quickly contaminate a building. A capability is needed to simulate CBR attacks, and to understand their impact on personnel, buildings, critical facilities, and other assets. An easy-to-use modeling and simulation tool, that provides visualization of the effects to buildings from an external release of such agents, could potentially provide support to force protection personnel, emergency responders, and facility planners.

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) developed an operable prototype tool for these purposes called CBRSim. As part of the Fort Future Virtual Installation project in 2005, Argonne National Laboratory was retained by ERDC-CERL to implement the CBRSim software, to develop the industrial chemical and leaky box modules, and to integrate them with the HPAC modules.

1.2 Objective

The objective of this project was to demonstrate the CBRSim application at a U.S. Army installation, and to provide its staff with the capability to run additional simulations.

1.3 Approach

ERDC-CERL collaborated with Fort Carson personnel to get project buy-in and to identify use cases. Ten buildings of interest were chosen for further focus on interior contamination. The team collected available GIS data, and established a Fort Carson model. ERDC-CERL also obtained assistance from researchers at the National Institute of Standards and Technology (NIST) to develop a methodology for assigning estimated building air change rates for the CBRSim model.

A workshop was conducted at Fort Carson for the force protection personnel to develop use cases, to run simulations, and to provide training on system operation. The lessons learned through the Fort Carson implementation were documented, in order to achieve successful technology transfer and application to other Army facilities.

A CBRSim User's Manual was developed for use at all Army Installations.

1.4 Scope

This project documents the demonstration of an alpha version of a software application program. The software is not considered to be fully operational for real-world threat modeling and simulation

1.5 Mode of technology transfer

The alpha version of CBRSim is not appropriate for fielding as a real-world simulation modeling tool for Army installations. However, it offers potential education and training benefits for first responders and installation Force Protection Officers by reinforcing the need to adhere to established emergency response protocols and visually adding to their insights about the effects and aftermaths of chemical, biological, or radiological weapons attacks.

The version of CBRSim documented in this study is considered suitable for transition to advanced developmental research an appropriate technical proponent.

2 CBRSim Development and Application

2.1 Program overview

The Defense Threat Reduction Agency (DTRA) has developed a software tool called Hazard Prediction and Assessment Capability (HPAC), which allows a user to enter release parameters, run an atmospheric dispersion model, and visualize contour plumes of human health effects of the contaminated outdoor air on an overlay of the user's installation (DTRA 2002). The original system focused primarily on Weapons of Mass Destruction analyses to be used by operational commands.

The CBR Modeling and Simulation (CBRSim) program provides a simpler front-end tool as a subset of the HPAC system. The tool allows a user to model the effects of a chemical, biological, or radiological incident within an installation, and displays the effects of using a shelter-in-place strategy on contaminant levels within buildings and their relationship with time.

The focus of CBRSim is to analyze hazards at and around an installation. It offers the more commonly used HPAC incident models and includes smaller-release scenarios such as an aerial spray release, or a tanker release/explosion. CBRSim also adds a leaky box model to simulate the shelter-in-place strategy, and to display its effects on contamination levels within buildings. The system can easily be set up to read ESRI (ArcGIS) shapefiles of any installation, including building footprints, road and rail networks, and topography. These files can be supplemented with building air change rates that are used to model outdoor air entry into the buildings.

CBRSim incorporates source terms for 23 weaponized agents (e.g., anthrax and sarin) from the HPAC Tool, along with an additional 44 toxic industrial chemicals (TICs), such as chlorine and ammonia. Data from external sources, including user input, provides initial state variables, such as amount of contaminants released, release rate, location, duration of the release event, and local meteorological information.

The basic work flow for the CBRSim is to define the source characteristics of a release, execute the air dispersion transport model, and analyze the health effects plots. The contour plots available are the 15-minute interval concentration plot, total integrated concentration (surface dosage), and surface deposition (see section 2.3, "Output").

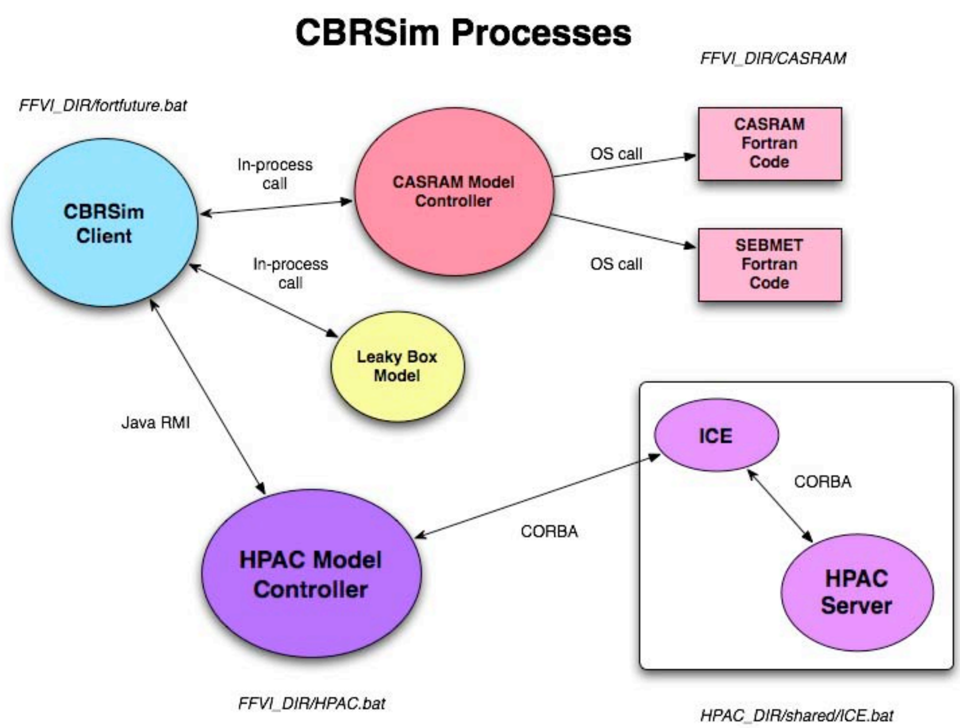

Figure 1. Processes used in the CBR Simulation.

Figure 1 shows the processes within the CBRSim system. DTRA's HPAC system (DTRA 2002) was designed for multi-user server interaction, and the architecture is such that its graphical user interface (GUI) desktop client is totally detachable. This allows the CBRSim system to make calls directly to the HPAC server components. The inter-process communication protocol that was chosen for calling the HPAC server application program interface (API) was CORBA (Common Object Request Broker Architecture). There is an Interface for Consequence Effects (ICE) layer API (ICI, 2003) so any external process needs to communicate with ICE in order to access the HPAC server functionality. The ICE layer also uses CORBA as its communication protocol. The CBRSim spawns its HPAC Model Controller as a separate process. The process wraps the subset of calls needed for this particular application. The HPAC Model Controller communicates with the CBRSim client via Java Remote Method Invocation (RMI), and packages data and makes the calls to ICE via CORBA calls. CORBA and Java RMI have the same purpose: to allow calling of methods within separately-running processes on a computer (or distributed computers).

Whereas the HPAC/ICE and HPAC Model Controllers run as external background processes waiting for input via CORBA or RMI, respectively, the CASRAM Model Controller and Leaky Box Models are written as internal Java models that reside within the CBRSim client process. The CASRAM and SEBMET models are existing models developed by Argonne National Laboratory (ANL) that are written in Fortran. As will be explained in the next section, CASRAM is the incident model for aerial spray releases and tanker/truck releases and SEBMET is the meteorological preprocessor that creates consistent meteorological parameters for use in both CASRAM and HPAC. In order for a Java program to call out to another language model, such as a Fortran model, it calls out to the Operating System and executes the model externally when needed. The input files for the Fortran models are written out from the user input in the client GUI, the model(s) are executed, and then the output files are read in and the results packaged for the HPAC model's execution. This processing is all invisible to the user.

2.2 Components

There are four major components to the CBRSim tool: Incident characterization modules, environmental data, air dispersion models and health effects plots, and an installation shelter-in-place protection strategy model.

2.2.1 Incident characterization models

Incident characterization models let the user describe the what, where, and when of a Nuclear, Biological, or Chemical (NBC) release and the models then calculate the associated material parameters needed to feed an atmospheric dispersion model. Three of the incident characterization models are included from HPAC. However, CBRSim employs a simplified user interface derived from the more sophisticated, but needing more expertise to configure, version within the HPAC system. A fourth incident model used is the CASRAM Model.

2.2.1.1 HPAC Models

The included HPAC models are:

- Chem/Bio Facility (CBFAC) – Used to calculate the amount of agent released to the atmosphere following a targeted attack at a chemical/biological facility. The user selects the calculation type, damage severity, agent, and mass of agent;
- Chem/Bio Weapon (CBWPN) – Used to calculate the amount and distribution of an agent released by a chemical or biological weapon. The user specifies the munitions type, weapon delivery system, agent, mass of agent in weapon, and the release altitude;
- Radiological Weapon (RWPN) – Used to calculate the explosive-driven dispersal of radiological materials. The user selects the high explosive mass, material type and form, radioactive material mass, calculation radius, exposure and cloud dose.

As pointed out previously, the HPAC incident models were focused on weapons of mass destruction, and require advanced expertise in setting up and selecting the numerous options when running in the original HPAC GUI. The CBRSim simplifies the user input by selecting defaults and exposing only the most necessary options. Therefore, the CBRSim user need not be an expert in CBR weapons in order to study the effects of an attack or accident on the installation. Detailed descriptions of the HPAC incident models, CBFacility, CBWeapon, and RadWeapon, can be obtained from the HPAC User's Manual (DTRA 2002).

2.2.1.2 CASRAM Model

The CBRSim system includes an incident model called Chemical Accident Statistical Risk Assessment Model (CASRAM), written at Argonne National Laboratory, to define chemical and biological releases from a tank car leak/explosion, or a spray release from a small plane. The CASRAM module also includes toxic industrial chemicals that are not included with HPAC for use in modeling the types of accidents or incidents at facilities that are more likely to occur. The CASRAM output is fed into the Second-order Closure Integrated Puff (SCIPUFF)(Sykes et al. 1998) dispersion model within HPAC, and health effects plots are produced for these runs just as if they were native HPAC modules. The following section describes the physical processing for the CASRAM model. Additional details can be found in Brown et al. (2005).

Materials are shipped or stored as either solids, ordinary liquids, compressed gases, or liquefied gases. The emission rate of the material to the atmosphere is largely dependent on the shipment state. Due to their low volatility, solids typically exhibit slow release rates. Consequently, with few exceptions, non-water reactive materials treated with CASRAM are liquids and gases at atmospheric pressure. These shipment states are illustrated in Figure 2, and are discussed below.

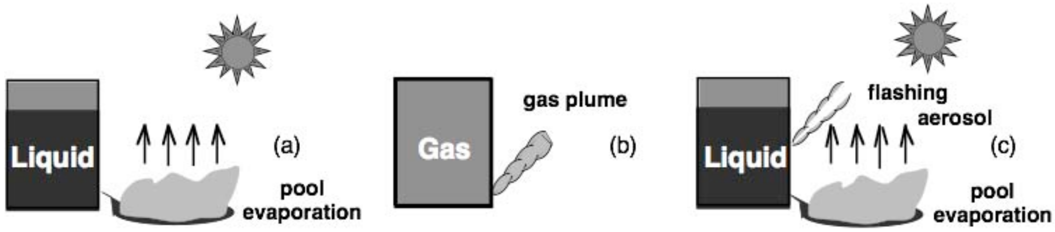

Figure 2. The three source types of importance for inhalation risk: (a) ordinary liquids, (b) compressed gases, and (c) liquefied gases.

Liquid materials are emitted to the atmosphere through pool evaporation as illustrated in Part (a) of Figure 2. The pool evaporation rate is dependent on many factors. For volatile liquids, the governing factors in determining the release rate, in approximate order of their importance, include: (1) vapor pressure of the liquid, (2) available energy, (3) pool size, (4) wind speed, and (5) atmospheric stability. In the case of low-volatility liquids (i.e., those characterized by low vapor pressure), meteorology replaces available energy in relative importance. Highly volatile liquids can evaporate very quickly (within minutes), cooling the pool in excess of 30°C below the ambient temperature. In such cases, the evaporating material can actually freeze, thus substantially reducing the evaporation rate.

Compressed gases are released in a so-called “blowdown” process, as illustrated in Part (b) of Figure 2. The blowdown process usually empties the container rapidly, and, in the case of severe accidents, may result in a nearly instantaneous release. All else being equal, release rates for compressed gases are many times higher than for ordinary liquids. The exception to this rule is minor valve failures, for which release rates may be very small.

The most catastrophic form of release involves liquefied gases, as is illustrated in Part (c) of Figure 2. Here, the release is broken into two phases. In the initial phase, denoted as the flashing and entrainment phase, a relatively small quantity of the material (usually 0-30% of the total) is instantaneously vaporized upon exiting the vessel, due to the sudden reduction of pressure. With rapid expansion of the material, the vapor typically entrains substantial quantities of the remaining liquid, forming an aerosol.

This aerosol usually evaporates quickly when exposed to air, cooling the vapor/air mixture to the point where the density of the mixture is often considerably heavier than air. Any liquid remaining after this process is deposited on the ground or surrounding surfaces, and is released through evaporation. Since the vapor pressures for such materials are usually well above atmospheric pressure, the evaporation phase is typically short, especially in comparison to the pool evaporation phase for materials that are liquids at atmospheric pressure. Due to the large quantity of material often involved, liquefied gas releases yield the largest release rates in comparison to liquefied and compressed gas releases.

The source component of CASRAM determines hazardous material release rates for each of the spill and/or vaporization scenarios described above. Pool evaporation within CASRAM is determined using a time-dependent energy-budget model that accounts for the key air-pool-ground energy fluxes that govern the evaporation rate. Heat transfer to and from the pool is treated via explicit consideration of solar radiation, air convection, ground conduction, and evaporative heat loss from the pool. The necessary transfer coefficients for evaporation are provided by a chemical property database, a preprocessed meteorological database, and output from SEBMET. Compressed gas releases are treated using semi-empirical blowdown relationships based on compressible-flow theory. Liquefied gas releases are treated by first calculating the flash fraction of the exiting material, and then determining the fraction of the remaining liquid that is entrained into the flashed vapor. This entrainment fraction is calculated using empirical relationships based on the discharge kinetic energy of the two-phase mixture. Released material that does not flash to vapor (and, that is not entrained in the vapor cloud) is assumed to deposit on the ground. Release of this deposited material is handled using the evaporation model.

As an aid in characterizing release scenarios and estimating release rates, the source model in CASRAM utilizes a database of the physical properties for over 300 toxic chemical compounds. For some material parameters, estimation of properties are used, due to the unavailability of experimental data in the literature. For transportation accidents, the current version of CASRAM contains statistical, empirically-based discharge fractions dependent upon container type and size, and transportation phase, that were developed using data contained in the Hazardous Materials Incident Reporting System (HMIS) maintained by the U.S. Department of Transportation. For fixed facility analyses, release parameters are entered by the user.

2.2.2 Environmental data

HPAC has a sophisticated module for input of the meteorological data needed to calculate accurately the dispersion of the agents. It can default to use historical weather data for the location, or ingest archive or gridded forecast data from DTRA's Meteorological Data Server (MDS). The CBRSim tool simplifies the necessity to apply for a DTRA MDS account or to look for alternate sources of meteorological data, by allowing the user to input a single surface observation consisting of temperature, wind speed/direction, relative humidity, cloud cover and cloud height.

The CASRAM model comes with a meteorological preprocessor model called SEBMET. This model takes a single meteorological observation, as input by the user, and calculates the needed meteorological parameters for use in the SCIPUFF dispersion model (discussed in Section 2.2.3). It has land cover/canopy data and climate data for the United States that it uses in its detailed calculations. The model takes the observation input and creates the meteorological parameters (every 15 minutes) for the duration of the HPAC modeling run. This output data is read in by SCIPUFF, which produces its output at 15-minute intervals for display. The following section describes the physical processing employed within the ANL-developed SEBMET model.

2.2.2.1 The SEBMET meteorological preprocessor

SEBMET contains two primary components: a surface energy budget (SEB) model that determines the surface-layer turbulence parameters, and an integral model that determines inversion height in convective conditions. Each component is briefly outlined below. For additional information on the meteorological preprocessor, including details on its development and validation, see Brown (1997).

2.2.2.2 Surface turbulence parameters

The surface-layer parameters are determined by using a SEB model that consists of parameterizations of the various SEB components and flux-profile relationships (equations that relate wind speed to friction velocity u^* and sensible heat flux). The goal of this modeling approach is to isolate the sensible heat flux H from the other energy budget components. The starting point for this analysis is the SEB at the ground. When advection, photosynthesis, and snow melt are neglected, the SEB is most simply represented as follows:

$$Q^* = H + \lambda E_w + G + Q_a$$

where:

Q^* = net surface radiative heat flux,
G = conductive soil heat flux,
λ = heat of vaporization for water,
E = evaporation rate (together, λE_w is the latent heat flux), and
Q_a = anthropogenic heat flux.

The net surface radiative heat flux is the residual from the absorbed solar radiation S, incoming long-wave radiation L^+, and outgoing long-wave radiation $\varepsilon\sigma T_S^4$. It is written as follows:

$$Q^* = (1-\alpha_s)\, S + L^+ + \varepsilon_s \sigma T_s^4$$

where:

α_s = surface albedo,
ε_s = surface emissivity,
σ = Boltzmann constant, and
T_s = surface temperature.

At the surface, the short-wave balance is always positive, while the outgoing long-wave radiation generally exceeds incoming long-wave radiation. The model is constructed by parameterizing each of the components in the SEB in terms of routinely observed meteorological observations and site characteristics. A brief description of the SEB component parameterizations is presented below.

2.2.2.3 Inversion height and boundary layer height

The inversion height in convective condition is estimated with a one-dimensional model of the atmospheric boundary layer based on the Driedonks slab model (Driedonks 1982). In the Driedonks model, as in similar models, the surface turbulence fluxes, $u*$ and H, are integrated over time so that the boundary layer evolves from an initial early morning height. The Driedonks model was chosen because of its comprehensive treatment of dynamics at the inversion, favorable comparison with field data, and ease of inclusion in the preprocessor.

In neutral and stable conditions, the boundary layer height is less well defined. Generally, the boundary layer height, at least in stable conditions, is taken to be the height at which surface-induced turbulence drops to a negligible value. Here, the diagnostic relations for stable conditions are used, defined by Nieuwstadt (1981), and provided by the neutral limit (h = $0.3u*/f$, where f is the Coriolis force), following the recommendations of Hanna and Paine (1989). (Hanna and Paine recommend that the neutral relation be used when L is greater than or equal to 100, and that Nieuwstadt's relation be used when L is more than zero but less than 100.)

2.2.3 Air dispersion models and health effects plots

2.2.3.1 Atmospheric transport model

HPAC includes an atmospheric dispersion model called SCIPUFF. The SCIPUFF model was written by, and is maintained by, Titan Corporation. This Fortran model represents the released agent as a series of Gaussian puffs in order to represent a 3-dimensional, time-dependent agent concentration field. It calculates the complex diffusion flow of the dispersing agent, taking into account effects from terrain topography, planetary boundary layer turbulence, and wind shear at multiple layers in the atmosphere. (See the SCIPUFF Technical Manual [Sykes, 1998] or the HPAC User's Guide [DTRA, 2002] for an in-depth discussion of the physics of these models.) The output from the SCIPUFF model is contoured, using threshold values for adverse human health effects, and is available for display on the CBRSIM JeoViewer map at each 15-minute interval of simulation time.

2.2.3.2 Leaky Box Model

During an outdoor release of a CBR agent, a building's indoor contamination levels are dependant on: the building outdoor air change rates and the contamination levels of that outside air. To model this dependency, the CBRSim system uses another ANL-developed model. This "Leaky Box" Model incorporates physical processes to calculate indoor air concentrations from an overhead plume, and models the effects during an incident from turning building HVAC systems on and off, and, from closing and opening windows/doors .

The building air change rate is a measure of the rate at which outdoor air enters the building. The air change rate of a particular building at a given time is a function of building layout, HVAC system design and operation, the operation of other building systems such as exhaust fans and vented combustion equipment, building envelope airtightness, and exterior weather conditions. A key simplification in this framework is that the building is represented as a single well-mixed box, meaning that the air within the building maintains a spatially uniform concentration.

Contaminant concentrations within buildings are calculated based on the time history of the outdoor concentration and the building air change rates. For each building, the indoor concentration is modeled, using the following equation:

$$C_{in}(t) = \int_0^t C_{out}(\tau) A_c \exp(-A_c(t-\tau))\,d\tau$$

where:

C_{out} and C_{in} = outdoor and indoor concentrations, respectively,
t = time, and
A_c = building ventilation rate

For constant C_{out} from 0 to T, the relationship for C_{in} reduces to the simple relations for one of the following equations:

when 0 > t > T: $C_{in}(t) = C_{out}(1 - \exp[-A_c t])$

when t > T: $C_{in}(t) = C_{in}(T)\exp[-A_c(t-T)]$

For many buildings, this is a reasonable assumption. However, as the building size and the number of rooms (and HVAC zones) increases, this assumption becomes less valid. Another assumption is that there are no chemical removal mechanisms such as chemical reactions and gas adsorption within the building besides the air change rate with the outside. However, such mechanisms would reduce the chemical concentrations in buildings, making the assumption to neglect these effects a conservative one.

The building air change rate is generally expressed in terms of air changes per hour (h^{-1}). For the leaky box model, the total building air change rate is taken as the sum of the outdoor air intake through the HVAC system and the rate at which outdoor air enters the building through infiltration.

For each building represented in the model, three air exchange rates can be set. These rates are referred to in the following section, as follows:

(A) HVAC air change rate, in normal mode of operation,
(B) Building envelope leakage rate, with doors and windows closed
(C) Building envelope air change rate, with doors and windows open.

2.2.4 Installation shelter-in-place protection strategy model

Shelter-in-place can be an effective protection strategy against CBR attacks. In an emergency, building air change rates can usually be reduced substantially by deactivating the ventilation system and closing windows and doors. CBRSim simulations employ a shelter-in-place scenario.

During model operation, we assumed building ventilation progresses through four stages for each building.

- Stage 1 (Normal Mode) is at the beginning of a simulation, before contamination reaches the building. The building HVAC system is assumed to be running at normal mode, with the windows and doors closed. (Building air change rate = A + B).
- Stage 2 (Shelter-in-Place Mode) is invoked once the contaminant plume reaches the building. The building HVAC system is turned off, and the doors/windows remain closed. (Building air change rate = B). During this stage, the building is flagged as contaminated, and the model will continue calculating the indoor/outdoor air change rate (every 15 minutes with HPAC outdoor concentration predictions), until the building's outside air contamination level reaches below minimum health levels as determined by HPAC.
- Stage 3 (All-Clear Mode) is then invoked, and the building HVAC is turned on with the doors and windows remaining closed. (Building air change rate = A + B).

- Stage 4 (Flushing Mode) occurs after an hour at which exterior contaminant concentrations remain acceptable. The HVAC remains on, and the windows and doors are opened (Building air change rate = A + C).

If another plume comes overhead, the whole process starts over.

2.3 Output

For an introduction to the CBRSim GUI, see the draft User's Manual (Appendix A).

Figure 3 shows the results of a simulation in-progress. It is paused to take a snapshot (as shown in the simulation control panel, bottom right). The JeoViewer is displaying the plume contours (Surface Dosage for Sarin as selected within the Display Control panel), the Thematic Legend is showing the plume contour values for Surface Dosage as well as the indoor air concentration calculated in the leaky box model by using the plume concentration values overhead of the building.

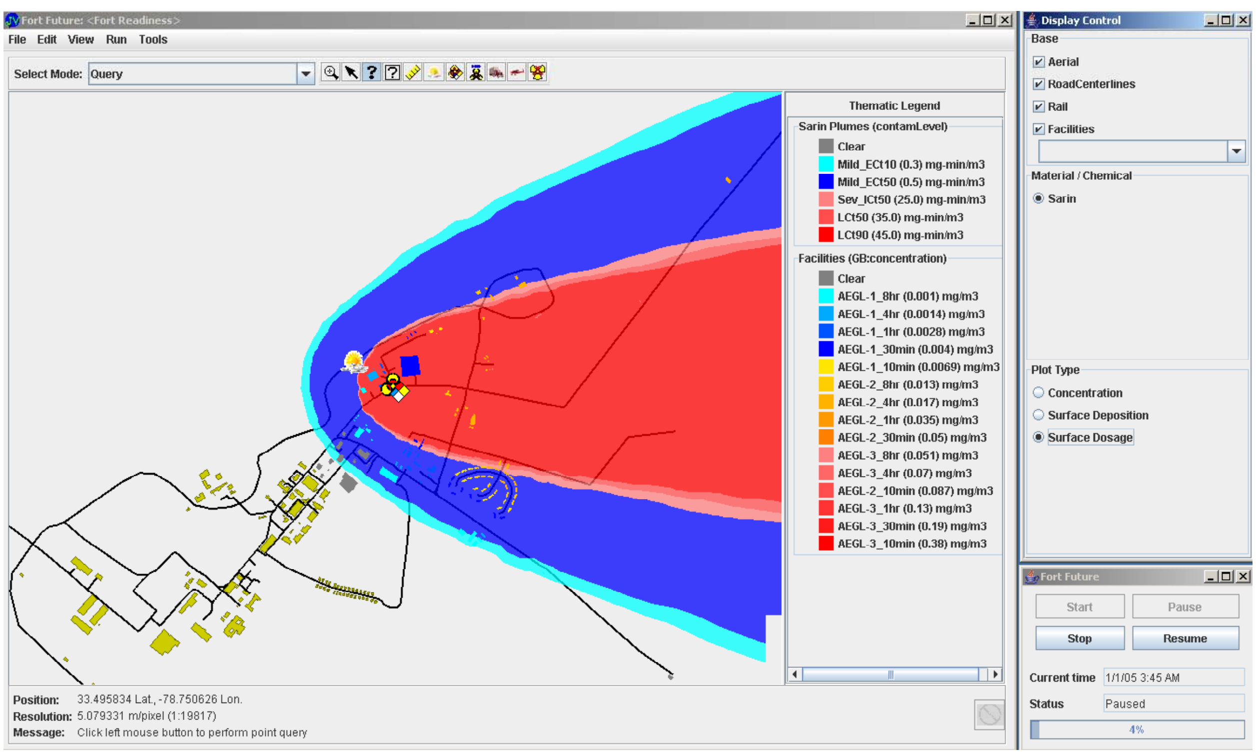

Figure 3. Simulation output shown on JeoViewer map with thematic legend, display control window, and simulation control panel.

The three types of HPAC-produced plots that are created for the CBRSim model are: (1) the concentration in air, (2) the surface deposition (on the ground), and (3) the surface dosage (integrated air concentration over time). The contour values shown in the Thematic Legend are colored/labeled with toxicity/health exposure thresholds, as typically used in emergency response scenarios. Different sets of thresholds are used for different agents. These thresholds include Acute Exposure Guideline Levels (AEGLs), Emergency Response Planning Guidelines (ERPGs), Immediately Dangerous to Life or Health (IDLH) levels and Temporary Emergency Exposure Limits (TEELs). These threshold criteria define concentration levels that are toxic to humans at three levels of severity. For many chemical and biological agents, exposure to a vapor or aerosol is measured from the surface dosage, and then quantified in a Concentration Time (Ct) category. The Thematic Legend labels may include LCt values (lethal dosage of exposed, unprotected personnel (e.g. LCt-50 is lethal to 50% of the personnel)) and ECt and ICt values (Effective and Infective dosage of exposed, unprotected personnel for biological agents and the Incapacitating dosage for chemical agents). For Surface Dosage (calculating the amount of mass deposited on the surface), the contour labels are shown as LD (as in LD-90 is the amount of liquid agent expected to kill 90% of the personnel).

For a detailed explanation of the HPAC-produced plots, refer to the HPAC User's Manual, (specifically the sections on Biological Agent Toxicity, NBC Human Health Effects and Related Plots, and Toxicity Level Contour Definitions).

The Query tool, shown in Figure 4, lets the user select items on the map and look at their attributes.

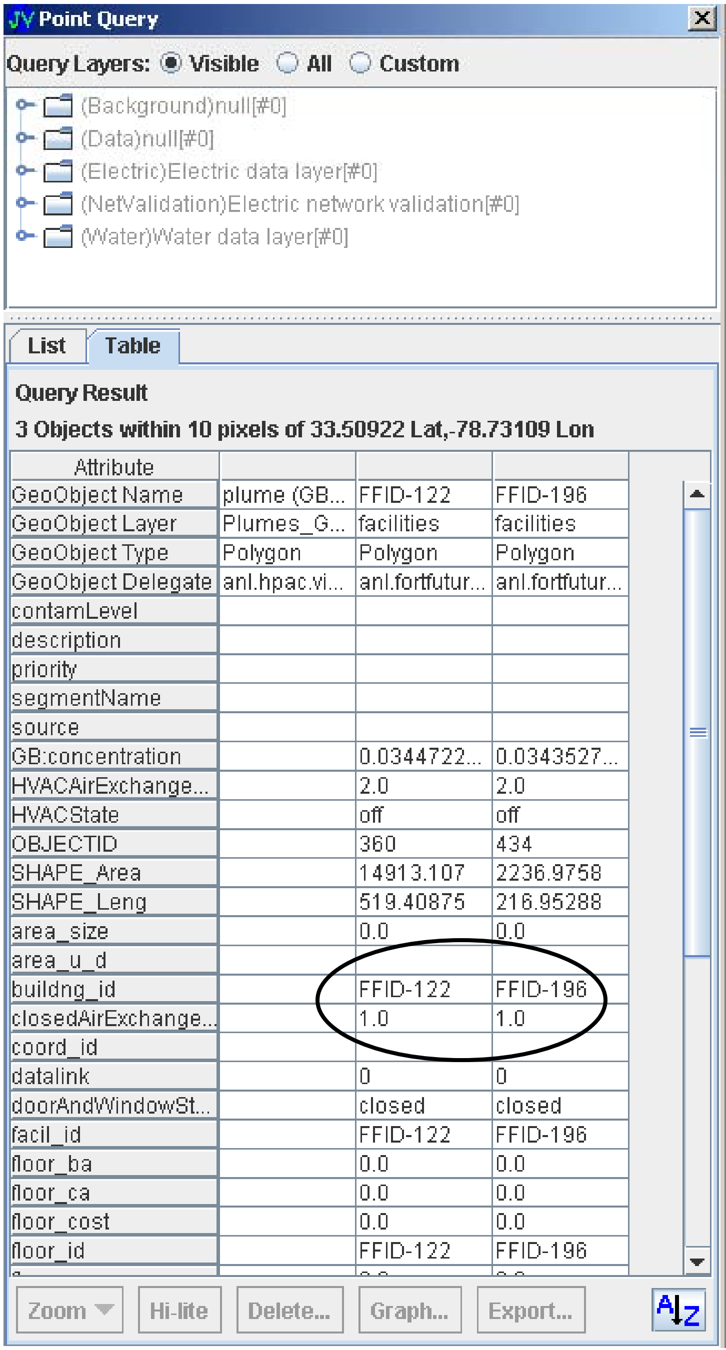

Figure 4. Point query, showing table of attributes.

Most of the attributes are from the ESRI shapefile/dbf file loaded in for the installation's facilities. Some of the attributes are created while the simulation executes. Notice the GB:concentration values (Sarin) for the 2 buildings selected (FFID-122 and FFID-196). Also, the HVACState, HVACAirExchange, closedAirExchange, and doorAndWindowState are all filled in while the leaky box model is running.

While the simulation is executing, the user can monitor certain buildings and switch between views of the types of plots. By using the Recording tool, one can make several runs of the same agent or different agents, and use the saved movies to compare/contrast the incidents.

2.4 Potential system users

Potential users of the CBRSim system are force protection officers, emergency response teams, and master planners. Unlike HPAC and other plume model software, CBRSim provides visualization changes in contaminant concentration within buildings, based on changing the building ventilation characteristics.

Force protection officers can use simulations to instruct building occupants on the benefits of shelter-in-place, and also get buy-in from managers on understanding and executing protocol in event of an external CBR release incident.

The system can also be used as a planning tool for emergency response planners (such as a Fire Chief). Master planners can run simulations of high-risk release scenarios, and make decisions on placement of facilities. As an example, if a toxic chemical were transported by rail at a high frequency, it may be undesirable to place high-risk targets (HRTs) or a mission essential vulnerable area (MEVA) in the vicinity or on the downwind side of prevailing air currents.

2.5 System implementation

Implementation of CBRSim at a site, such as a military installation, requires collection of Geographic Information System (GIS) data, establishing building air leakage parameters for buildings of interest, and development of the installation model.

2.5.1 GIS data collection

Applying CBRSim to installations or sites that do not yet have GIS data requires only minimal data collection. If an installation has GIS data for its facilities, then the bare minimum data is already available to implement the model and application. If an installation lacks GIS data for facilities, the necessary data can be rapidly created using standard GIS tools and available maps, or aerial photography.

CBRSim was designed to be installation-independent, meaning that it can readily be configured for any installation by providing a few necessary ESRI shapefiles.

Only two GIS datasets are needed for development of the model:

- Road network (centerlines of primary and secondary roads)
- Building footprints facilities to be included in the model (with or without HVAC parameters specified)

Adding additional facility attributes provides greater analytic capability, but are not necessary for running the model.

As part of installing the CBRSim software, a "Fort Readiness" template is placed in the program directory. This template is used as a starting point to generate the installation model. By copying the directory structure for Fort Readiness, and replacing the above shapefiles with files of the same spatial projection, the CBRSim can be "relocated" to the particular installation being modeled. Section2.5.3 provides details about setting up a new installation, and Appendix A provides detailed descriptions of the files involved.

2.5.2 Building air change rate data

As mentioned previously, three building air change rates (A, B, and C) are used to determine the building contamination concentration at different stages during a simulation. These values can be put into a model in two different ways. Default values have been preloaded into the shapefiles and apply to all buildings. These default values (in air changes per hour) are: A = 2, B = 0.5, and C = 2. However, if better estimates are preferred for particular buildings of interest, the user can also specify different values for those, and enter them in their respective shapefiles.

For this purpose, a 12 tables have been included in Appendix B to provide air leakage estimates for different classes of buildings (single-family homes, schools, barracks, warehouses, etc.), for different relative levels of building airtightness, and for severity of weather. These tables were developed based on American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1, a limited amount of collected data, and engineering judgment derived from energy and building air leakage investigations conducted by the National Institute of Standards and Technology (NIST).

2.5.3 Model development

To model a new installation requires geospatial data be placed in specific locations with specific formats. (See the CBRSim Directory and File Structure section in Appendix A for a description of the overall files used in the system.)

To change the Fort Readiness version to represent a specific installation requires replacing files created during program setup with installation-specific data (see Appendix A).

There are two ways to accomplish this:

1. This is most simply done by converting file formats and renaming installation data, consistent with the existing data types and names. This entails possibly re-projecting geospatial data and may result in a less accurate geographic representation. For most installations using the model for planning, however, the impact of this additional inaccuracy would be negligible. The expected projection is UTM Zone 13, GRS 80, units expressed in feet.
2. The other option will result in a model with more geospatial accuracy, but requires editing model-related text files. This requires changing the projection specification files to reflect the projection used in the installation data. To change the projection specification requires editing text files (readiness.dat, readiness_centerlines.dat, and readiness_facilities.dat). The parameter within each file, Projected Projection, may be edited to specify a different UTM Zone.

The installation files are under the GeoData directory.

The readiness_centerlines.dat file is the file used when loading the road network. The expected projection is UTM zone 13, units in feet and consists of polylines representing the center lines of the installation's road network. The NameField of ROAD_NAME is the column header (in the corresponding dbf file) used to identify the road segments. Be sure it matches the name in your dbf file. In the case of Fort Readiness, primary and secondary roads are loaded. The expected filenames are: trveh_road_primary_centerlines.shp and trveh_road_secondary_centerlines.shp, respectively. Copy your road network files to the network directory.

The readiness_facilities.dat file describes the facility footprint shapefile.

Projection is assumed at UTM zone 13, units in feet. The NameField here is important in that it must correspond to the column header of the unique identification (ID) for the buildings in your file. Facilities without unique IDs or duplicate IDs will not interact with the plume model. You may notice this when running the model as buildings that do not change color on the JeoViewer map when a plume is overhead. FACIL_ID is the column header that contains the data for expected unique IDs. The unique ID "NR" is reserved, and any facilities assigned this ID will be skipped by the model. The expected filename is: bggen_structures.shp. Copy your facility shapefiles to the facilities directory.

Facility data may be assigned air change rate values. If these values are missing or the fields are not provided, default values are used. If the fields are provided and zeroes are specified, the zero values will be used. To use the defaults, ensure that the fields are not provided, or put the defaults into the fields. Air change rates may be specified for the HVAC system (A), building envelope leakage with open windows and doors (C), and building envelope leakage with closed windows and doors. The expected field names are:

- Unique ID: "FACIL_ID"
- HVAC air change rate: "EXCH_HVAC"
- Open windows and doors air change rate: "EXCH_OPEN"
- Closed windows and doors air change rate: "EXCH_CLOSE"

The LayerDefinition in layer_defs/Background.def is used to render the shapefiles and other data shown on the map. There is no mandatory editing required for the Background.def file.

3 CBRSim Demonstration at Fort Carson

3.1 Model development

ERDC-CERL developed a Fort Carson model for the CBRSim computer program using installation-specific data. To accomplish this, the research team met with utility to installation force protection officers, emergency responders, and DPW personnel to provide a briefing on the tool and its capabilities. Installation geospatial data, in CAD format, were obtained for select buildings, roads, and topographic features in order to locally calibrate the model, and 10 buildings were selected as the focus of the Fort Carson simulation. The ERDC-CERL team performed visual inspections of the selected buildings, and Fort Carson personnel collected data for estimating air exchange rates.

Upon receipt of the localization data, the Fort Carson CBRSim model was developed largely following the steps described in section 2.5.3. To provide additional geospatial context, topographic data was included in the visual display. The topographical information, which were furnished at high resolution with point, line, and polygon data, was processed from .DGN CAD files into ESRI shapefiles for contour lines at five-foot intervals. All data were projected to UTM Zone 13, with the units expressed in feet.

The building data were further modified to include air exchange values. Appendix B describes how default air change values were developed. For 10 selected Fort Carson buildings, air change values were established using the methodology provided in Appendix B, and the shapefile data table was accordingly customized. The remainder of the Fort Carson buildings were specified with the default values (air changes per hour of A = 2, B = 0.5 and C = 2) as discussed in section 2.2.3.2 (HVAC air change in normal mode of operation (A), building envelope air change rate with doors and windows closed (B), and building envelope air change rate with doors and windows open (C).

Following this data processing, the files were copied into the appropriate directories for the CBRSim application, resulting in a CBRSim model specifically customized to Fort Carson. While an installer was created to hand this model to Fort Carson, the installer developed for Fort Readiness and the data manipulation detailed in section 2.5.3 is sufficient to customize CBRSim to another installation.

3.2 Workshop

3.2.1 Attendees

As part of this project, ERDC-CERL researchers visited the Force Protection Office at Fort Carson to lead a workshop using the CBRSim tool configured with the Fort Carson model. The purpose was to solicit input from prospective users about the software design, uses, and capabilities. Attending was the Fort Carson CBRNE Operations Specialist, who was given a briefing on the functions and use of the tool. CBRSim was installed on a non-networked laptop computer and simulations were run under varying scenarios and parameters. Due to installation security requirements, neither that data nor its representations are provided in this documentation. The CBRNE Operations Specialist provided user feedback and collaborated with the team about lessons learned. The ERDC-CERL team then provided an outbrief to the Chief of Plans and Operations, the Plans and Exercise Supervisor, and the Senior CBRNE Operations Specialist.

3.2.2 Lessons learned

The following lessons were learned from the Fort Carson CBRSim demonstration:

- Time-stepped visualization is very useful for demonstration to other groups, such as emergency responders and facility managers. This may facilitate appropriate planning and response.
- Time-stepped visualization should allow the user to pause, step forward and back at appropriate time increments to easily see where a contaminant plume was, is, and where it is going.
- Selection of hazard parameters (material type, quantity, containers, etc.) should be automated (if connected to sensors), or should be simplified (provide icons and easy access to instructions), particularly if the tool may be used by emergency responders. In emergency response, inputs should parallel data likely to be available in an emergency.
- Visual displays should offer the ability to show building numbers and road names and other significant information that helps to orient the user.

- Visual displays should allow the user the ability to modify what is displayed, to include turning certain information on/off, such as geospatial data or contaminant information.
- Installation-oriented threats, such as improvised explosive devices (IEDs) and backpack bombs, must be included in the modeling capability.
- Measurement unit specification should be flexible based on user-requirements (for example, do not require the user to convert to or from metric).
- Weather parameter specification should be automated or simplified to allow easy user access to specifying defaults for a given simulation.
- Software installation and local configuration instructions should be reasonably simple and clear, requiring minimal technical support.
- Software displays should be presented logically, based on intended use (e.g., emergency response or planning) of the model by default.
- Visual representation of exposure to contaminants should be easy to interpret, and a “click-on” or “roll-over” textual interpretation of the visual representation should be provided to help explain, for example, the lethality or contagion of an exposure indicated for a “red” coded facility.

4 Conclusions and Recommendations

4.1 Conclusions

As part of this demonstration, a methodology based on "rules of thumb" was developed to help provide building air change rates with outdoor air for use with the CBRSim "leaky box" simulation model. This methodology was intended to make it possible to customize model parameters in order to simulate the results of CBR attacks on specific buildings. A draft user's manual was also developed.

At this stage in its development, the CBRSim software tool is not ready for validation with respect to building air exchange. Therefore, use of the tool should be confined to educational, training, and software development activities, and it should not be considered to be reliable or field-ready.

However, because of its ease of use, minimum data requirements, and versatility in providing a visual display of both indoor and outdoor contamination levels, it can be useful in installation planning, and in training both building managers and emergency response teams.

4.2 Recommendations

The alpha version of CBRSim documented here should not be considered field-usable for a reliable, detailed simulation of the effects of a CBR attack on real-world facilities. In particular, CBRSim should not be used for vulnerability assessment, or for decision-making or response to an actual incident until the simulation model and software is validated in terms of air exchange and transfer of contamination between the building interior and surrounding outside air.

However, because the alpha version of CBRSim is easy to use, has minimal data requirements, and provides a versatile display capability for illustrating both indoor and outdoor contamination levels, it could be useful both for incident planning and for training building managers and emergency response teams. For example, CBRSim could be used in conjunction with training exercises for emergency responders such as hazardous materials teams, paramedics, firefighters, and law enforcement personnel to provide insights into how to deal with alternate hypothetical incidents. Simulation results could be used to help evaluate the speed and effectiveness of first responder protocols and activities. It could also be used as an educational tool by the installation Force Protection Officer and others when training facility personnel, supervisors, etc., on the importance of shelter-in-place measures and having established incident protocols. The Officer also could make building visits and run simulations for any personnel responsible for the safety of building occupants (administrators, teachers, etc.) to illustrate the benefits of shelter-in-place procedures.

It is recommended that modifications to the user interface be considered in response to feedback received from users and other input from researchers.

It is recommended that CBRSim be considered for technology transition to an appropriate advanced development program such as the Installation Protection Program under the Joint Program Manager Guardian. Further development should include systematic validation studies to address the alpha version's current insufficiencies for use in actual planning and response activities.

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Appendix A: CBRSim Draft User Manual

Table of contents

Quick start guide

1. You must first have the following installed on your system; these are not provided on the CBRSim Installation CD:
   - Hazard Prediction and Assessment Capability (HPAC) 4.0.3 update
   - HPAC Interface for Consequence Effects (ICE) *HPAC requires a license from the Defense Threat Reduction Agency (DTRA) http://www.dtra.mil/rd/programs/acec/index.cfm. ICE is an object-oriented interface to HPAC, written by Science Applications International Corporation (SAIC) for DTRA.*
2. Insert the CBRSim Installation CD or open the .zip file. Execute **FFVI_Readiness.exe** to install the CBRSim application. *You must have administrator rights to install CBRSim.*
3. Installation will prompt you to replace HPAC material files (a backup will be made). For full functionality of CBRSim, replace the files.
4. Choose the installation directory and complete the installation.
5. Double-click the **Fort Future Readiness Model** icon on your desktop or navigate Start>All Programs>FFVI>FFVI_Readiness>Fort Future Readiness Model. All necessary components of CBRSim will open. *To properly run CBRSim, you must have read/write permissions for the HPAC and CBRSim folders.*
6. Click the arrow button (icon) on the map to cause the map to re-center on your click. Right-click on the map to select other zoom options. Use the magnifying glass icon to zoom in on an area. Use the query tools icons to open attributes about individual or multiple map features.
7. Choose a CBR Icon and click anywhere on the map. Input parameters for the CBR incident. Choose the sun icon, and click on the existing meteorology input, or insert another, then choose the weather parameters.
8. Select **View>Show Thematic Legend** and then **Tools>Display Control**.
9. Select **Run>Run Model**, wait, and observe the plume and its interactions with the facilities. You may continue using the map, though interaction with the map may be slow.
10. See the complete documentation for additional details.

System installation

The CBRSim Installation CD contains the installer for the Chemical/Biological/Radiological Simulation System (referred to as CBRSim). However, before installing the CBRSim software, please make sure the following software packages have been installed:

- Hazard Prediction and Assessment Capability (HPAC) 4.0.3 update
- HPAC Interface for Consequence Effects (ICE)

HPAC requires a license from the Defense Threat Reduction Agency (DTRA) http://www.dtra.mil/rd/programs/acec/index.cfm. ICE is an object-oriented interface to HPAC written by Science Applications International Corporation (SAIC) for DTRA.

After the HPAC4 has been installed with 4.0.3 update, run the install.exe executable to install CBRSim on your machine. The installer will ask for the location of the HPAC4 installation directory as it needs to reference files there. An installer is provided for a fictional Fort Readiness, which may be adapted to a real installation. You will be asked where you would like to install FFVI (root directory referred to as FFVIroot). The default for the FFVIroot directory is C:\Program Files\FFVI_Readiness.

The installer will prompt the user to replace the HPAC material files; this is recommended. The CBRSim system required additional agents and corrected others within the original HPAC installation. The original material files will be zipped up before the edited ones are copied to the HPAC installation\server\data\materials directory. If you choose not to install the edited material files, parts of the CBRSim may not work properly.

The installation script will put a DOS batch file fortfuture.bat file installed in the FFVIroot directory. A shortcut icon is placed on the desktop, labeled Fort Future Readiness Model as well as put into the Start Menu. Double-clicking on this icon will launch CBRSim along with the HPAC and ICE servers (those processes have no GUI and run in the background, the only visible sign is associated DOS windows with log messages for these processes).

CBRSim user interface

Main window

When the CBRSim starts, installation data and the software for selected modules will be loaded. Once the installation data and software for selected modules are loaded, the main CBRSim window will appear (Figure A1). The CBRSim main window will default to display the entire installation database. At the top of the main window there are menu items (File, Edit, View, Run and Tools) and a collection of icons used to select a mode (a particular CBRSim function). At the bottom of the main window, information about the 1) geographic location of the curser, 2) resolution of the current geographic view, and 3) status of the selected mode are displayed. This main window is based on the Argonne National Lab-developed Object Oriented GIS spatial visualization tool called JeoViewer. Since the CBRSim client (main window) is a separate process from the ICE/HPAC and they communicate via CORBA (see Figure 1 CBRSim Processes), 4 DOS windows appear along with the main window. These DOS windows should not be closed, but may be minimized to the task bar. The DOS window processes are:

tnameserv.exe – The is the CORBA naming service (like a yellow page listing) where the processes that need to communicate look up each other's "address" in order to connect and call methods between themselves. It should indicate that the port is set to 1400 and Ready.

ICE.bat – This is the window associated with executing ICE. This bat script also starts the HPAC services. Log messages are written to this window from the various HPAC services (e.g. CBWeapon, Scipuff).

java.exe – a DOS window associated with another service from HPAC (it ends with Listening on port: 1099).

HPAC Model Controller – This is the window associated with the HPAC Model Controller process which communicates via RMI with the CBRSim client and via CORBA with the ICE process. When the system if first started, it should say the it is waiting for connections. While the simulation is executing, it will show log messages on the status of the run.

Fort Future Client – lastly, the DOS window associated with the CBRSim main window pops up. The window is used for logging messages from the client Java process.

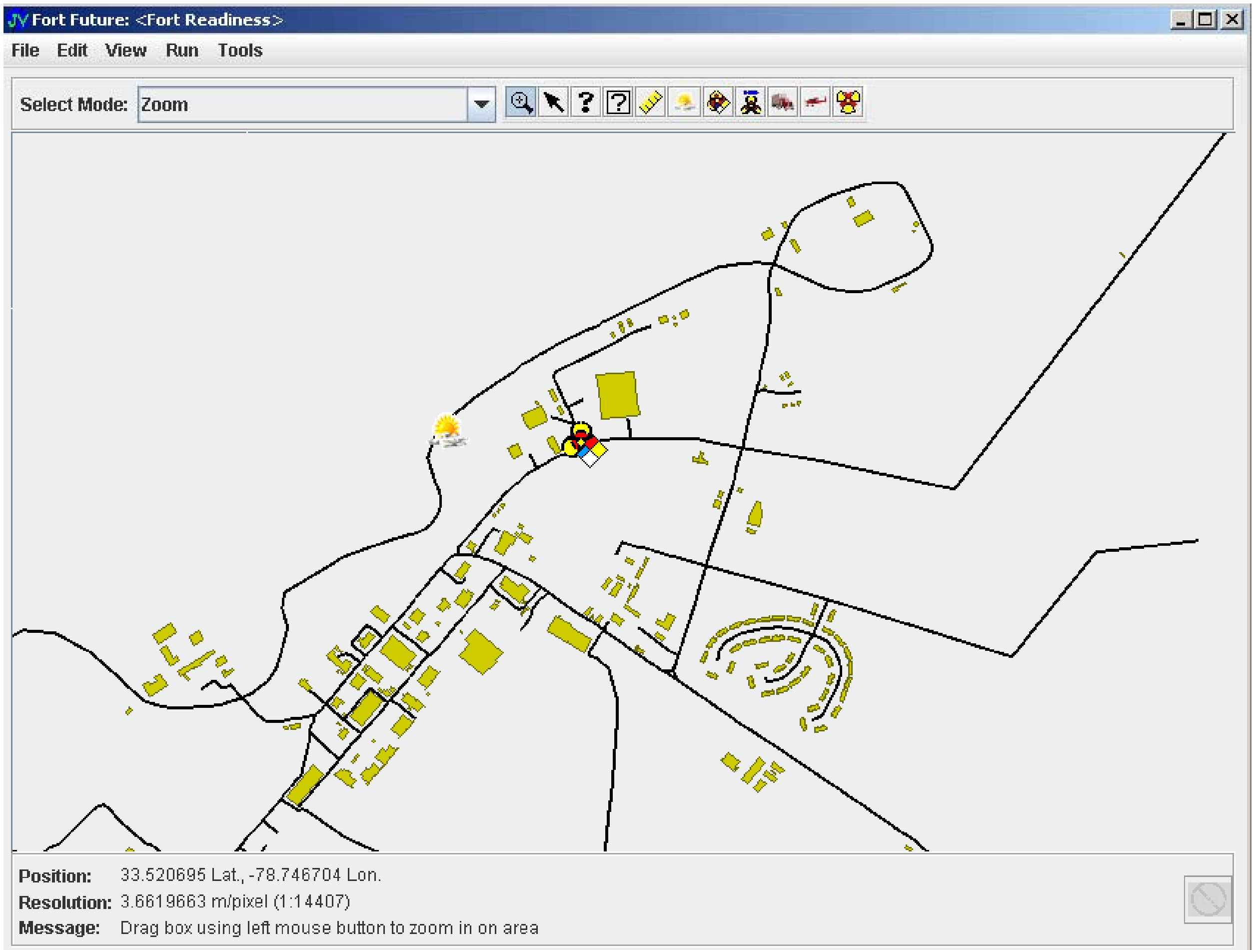


Figure A1. CBRSim main window, showing Fort Readiness.

Menu items

Across the top of the Main Window, there are five drop-down menus: File, Edit, View, Run , and Tools.

File menu

The file menu contains two options:

- About: Displays information on the CBRSim software
- Quit: Exits the CBRSim software

Edit menu

The edit menu contains one option at this time:

- Close Charts: Closes activity charting windows (which will only be set when running a the installation process model within the simulation).

View menu

The view menu contains five options:

- Zoom Out: Rescales the display by zooming out.
- Zoom Scaled: Contains a submenu where the user can choose to rescales the geographic display by zooming in or out by 2,5,10,or 100 times the current display scale
- Zoom Entire DB: This resets the geographic display back to the entire installation database.
- Redraw Map: Redraws the geographic display using current settings.
- Show Thematic Legend: Displays a thematic legend for spatial results from CBRSim simulations. The legend is automatically generated from the data being displayed (e.g. plume concentrations, building (facility) contamination status).

Run menu

Run Snapshot Recorder: Brings up the CamStudio application for recording the simulation. CamStudio is an open source screen capture utility included with the CBRSim. Its intent is to record a simulation for future playback and comparison to subsequent simulations with varying runtime parameters. Figure A2 shows the main window of CamStudio after selecting the Snapshot Recorder in the Run Menu.

Figure A2. CamStudio main window.

Within the CamStudio application, the first thing to do is to set the Frames per Second (fps) for recording the video. The default is 20 fps, but this is too frequent for recording these types of simulations and therefore should be set to a smaller fps to reduce file size of the movie file. Do this by selecting Options->Video Options. To get 4 frame per second, for example, slide the Time Lapse bar to the right at stop when the Capture Frames Every 15000 milliseconds shows (see Figure A3). Refer to the CamStudio Help manual for further explanations of video settings.

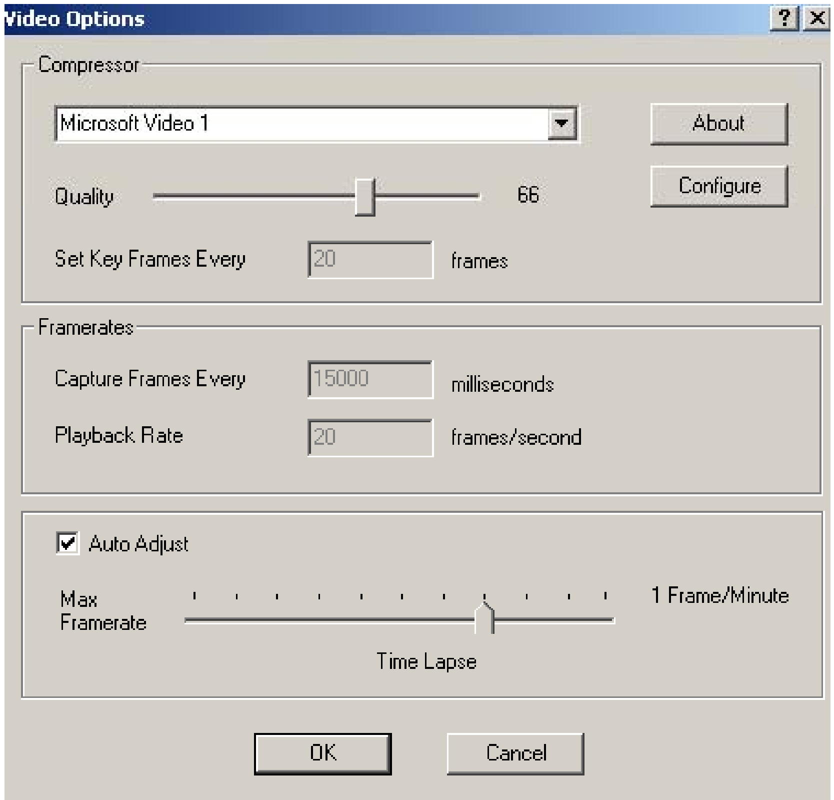


Figure A3. Video options window for CamStudio.

The second thing to do is to set the recording region. Select menu Region->Region. This will prompt you to define the rectangular region before recording starts. Use the rubberband box to outline the area on the computer display that you want to record during the simulation. The cursor turns into a pen with cross-hairs to define the region.

You may choose to record the full screen if you would like to show the other windows during playback (such as the Display Control and Simulation Control windows). Otherwise, be sure to Select the View->Show Thematic Legend on the main CBRSim window so that the legend is captured along with the geospatial map.

When you are ready to record (after you have set up your scenario, defined releases, and brought up the Simulation Control window (via Run Model [see below] and the Display Control window), press the Record Button on the CamStudio window. At this point, if you set the Region to record to region, it will change the cursor to the cross-hairs for outlining the window area. If you chose full screen, it will start recording.

Start the simulation executing by selecting Run->Run Model from the CBRSim main window.

Run Model: Runs a simulation based upon parameters the user has input into one or more of the CBR incident models. Figure A4 shows the Simulation Control window that comes up for controlling the execution.

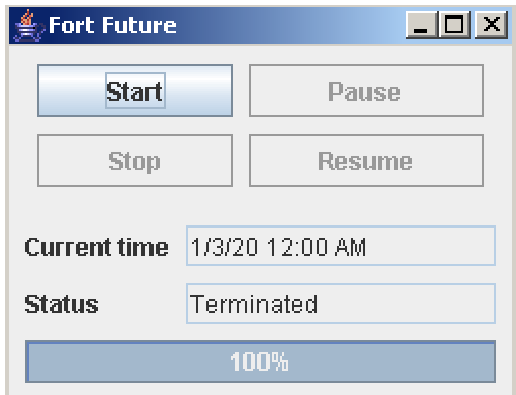


Figure A4. The simulation control window.

The simulation will call the CASRAM/HPAC models every 15 simulation minutes and will produce plots that will update on the screen.

If you are recording the simulation, you may zoom in/out and change which plume to view while it is capturing the screen. The CamStudio will need to be stopped after the simulation is done (or if you no longer want to record due to the plume being out of the area of interest). To do this, press the Stop button on the main CamStudio window. It will prompt for a file name and location to save the .avi movie file to. The CamStudio Player window also comes up after you've saved a recording.

Once an .avi file is saved, you can start CamStudio externally by finding Player.exe in the CamStudio directory of your CBRSim installation. Open the saved .avi file from the File Menu and control playback like a video recorder.

Lastly, you will need to exit the Recorder and/or Player separately from exiting the CBRSim main window, since it is a separate application.

Tools menu

- **Layer Manager:** The JeoViewer Layer Manager is rather cryptic and comes with CBRSim as part of using JeoViewer for the spatial display. Figure A5 shows a snapshot before the simulation is executed. It is a control panel for turning on and off layers in the main map view. The much simpler Display Control window was created for CBRSim use, so the more complicated Layer Manager is not really needed.

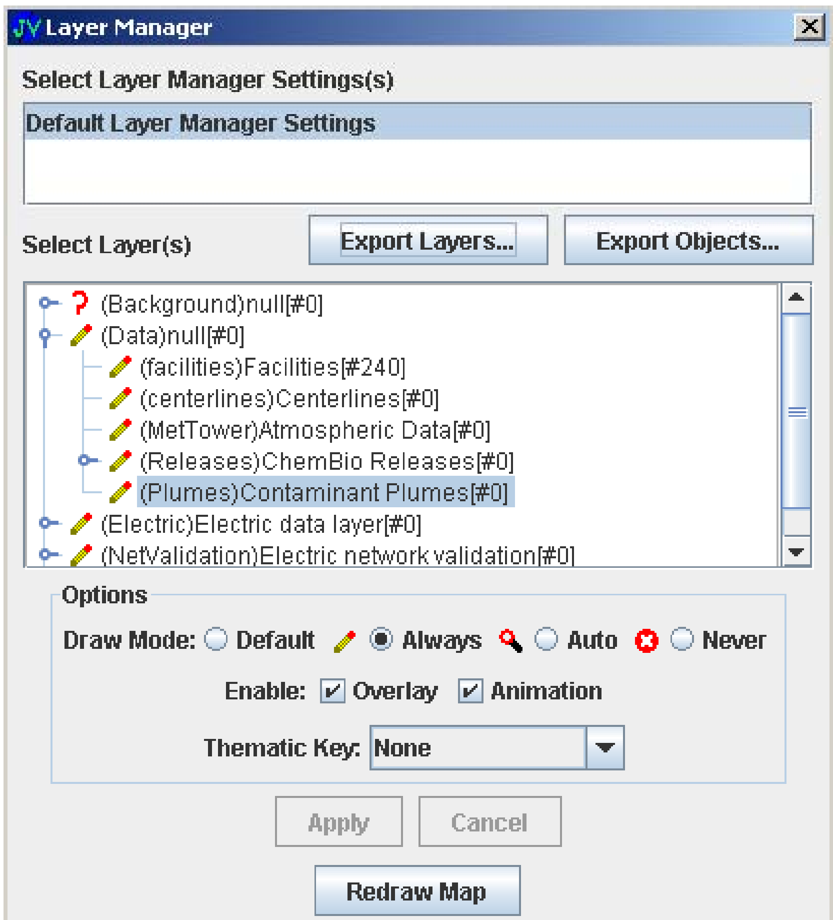


Figure A5. JeoViewer Layer Manager window before simulation execution.

- **Display Projection:** The Display Projection option is used to change the projection used to draw the map. To change the map projection being used for display, select from the list of available display map projections (XY, Polar Stereographic, Lambert Conformal Conic, Mercator, and Transverse Mercator). Depending on which projection the user chooses, other information will be required (e.g. zone, ellipsoid name). Figure A6 shows the Display Projection Window.

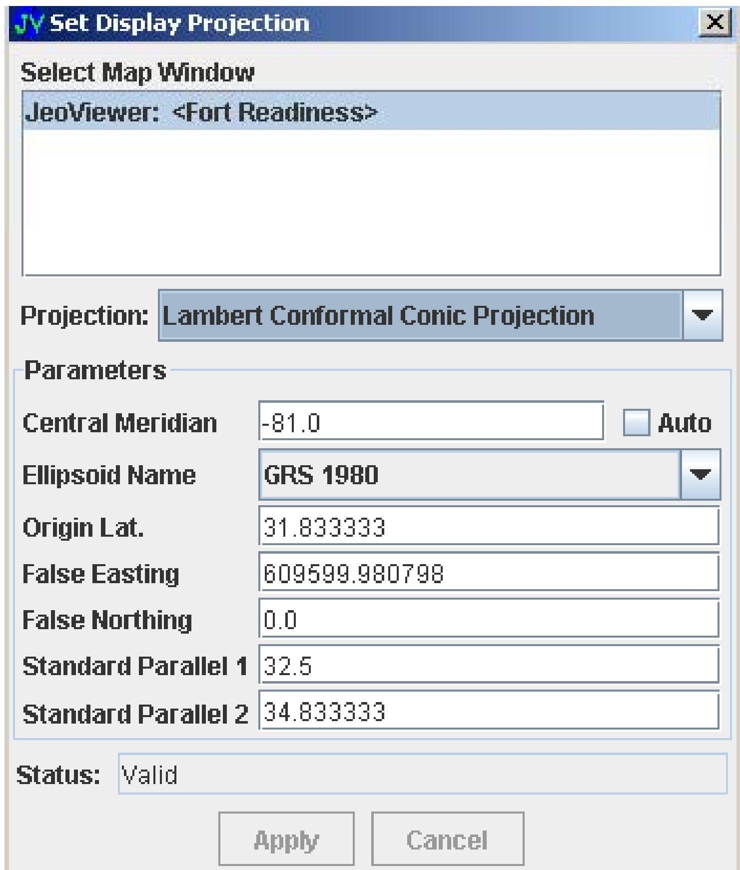


Figure A6. Display Projection window showing the projection parameters for the Fort Readiness shapefile data.

- **Display Control:** The Display Control window is used to control the layers that are displayed on the JeoViewer (Figure A7). It is handy to turn on/off base map layers such as the Aerial photo (if the facility has Mr Sid data, it can be displayed), so that you can see the facilities and roads better. By clicking on the corresponding checkbox, the layer will either display the layer or not.

The other two sections, Plot Type and Material / Chemical, are used only for CBR Simulations. They will come up blank before the start of a CBR Simulation run and are dynamically updated whenever plots are created by running SCIPUFF. The user can select only one plot type (choose from Surface Dosage, Surface Deposition, or Concentration plots) and one material/chemical release at a time. If the user wishes to view another material/chemical or plot type, simply check the radio button for the alternate selection during simulation and the JeoViewer will change to view a the selected material/chemical or plot type.

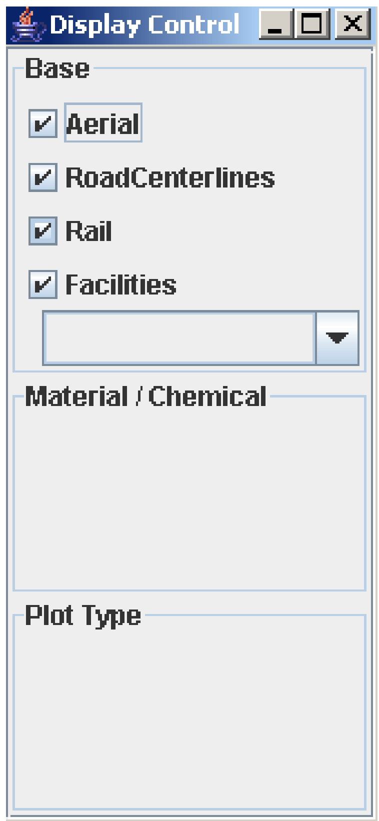


Figure A7. Display Control window before simulation executes.

- **Animation Control:** The animation control window only appears in the Tools menu when you are running the simulation. Figure A8 shows the window after the simulation has started, and the Animation Control menu is selected from the Tools menu. The current simulation time is shown in a non-editable text field. The Simulation Update Interval is the time (in simulation units) to have the JeoViewer display update. The Animation Pause Interval slider bar tells the JeoViewer how many seconds (in clock-time) to pause the animation of the map between display updates.

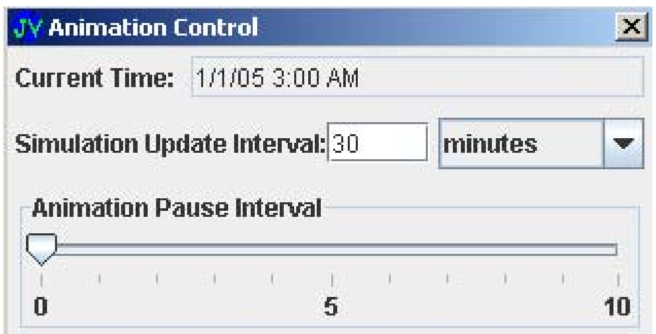


Figure A8. Animation Control window, shown during simulation execution

Mode Selection

In CBRSim, a user can enter a specific mode (specific CBRSim function) by either selecting that mode from the “Select Mode” drop-down menu or by clicking on the icon associated with the mode (the modes related to each icon are displayed if you hover the curser over the icon for a few seconds). Note that a message (or instructions) on how to use the mode are provided at the bottom of the CBRSim Main Window. Figure A9 shows the “Select Mode” dropdown menu (with “Atmospheric Data” selected) and a series of icons that can be clicked to change modes.

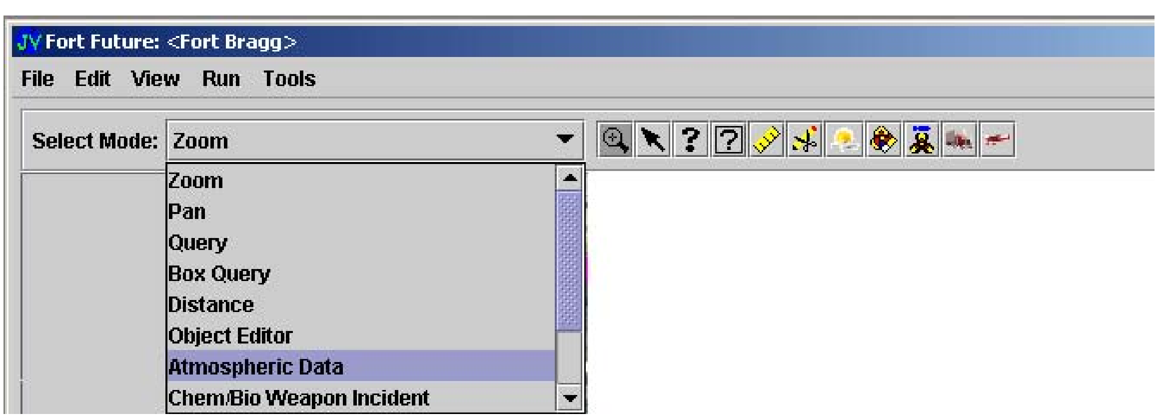


Figure A9. “Select Mode” drop-down menu and icons.

To verify what mode is assigned to each icon, place the cursor over the icon and a window will pop up identifying the mode associated with the icon. Figure A10 shows the window that pops up if you leave the curser over the "Atmospheric Data" icon for a few seconds.

Mode selection for CBRSim can be generally grouped into two categories:

- Navigating/Controlling the JeoViewer
- CBR Setup

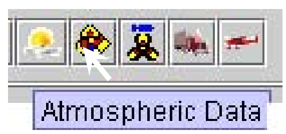


Figure A10. Pop-up Tooltip describing icon mode.

Navigating / Controlling the JeoViewer

There are five modes of functionality in the JeoViewer related to navigation and control:

- **Zoom Mode:** indicated by the magnifying glass icon (), is the default mode. Clicking on the icon or selecting "Zoom" in the drop-down box will put the JeoViewer in Zoom mode. While in this mode, you can click on the map to indicate the upper left of a rubber band box, and drag down to the lower right. Letting go of the mouse will then make the JeoViewer zoom to the indicated zoom box (Figure 11).

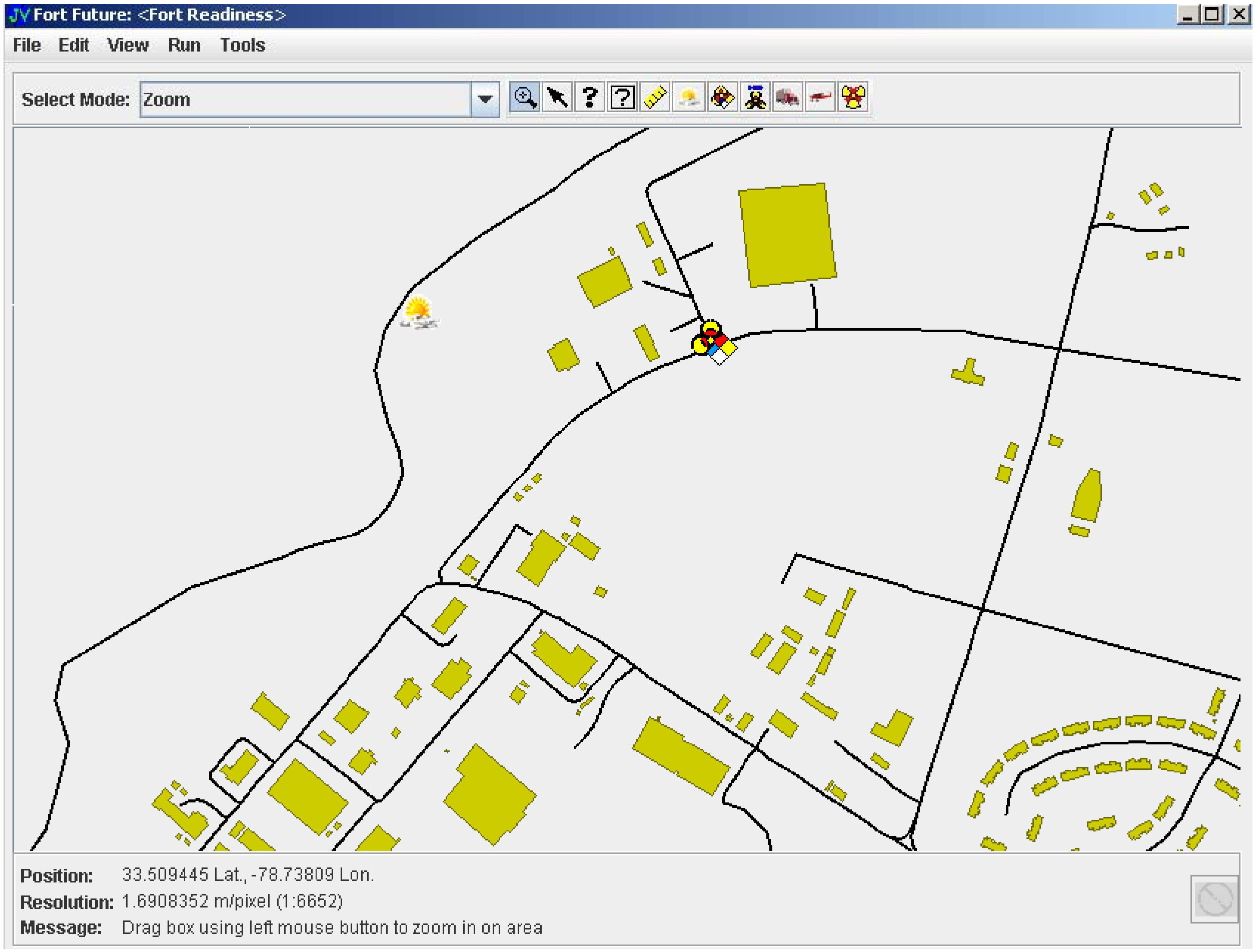
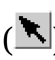


Figure A11. The JeoViewer view after a zoom action.

- **Pan Mode:** indicated by the arrow icon (). By pressing the icon or selecting “Pan” in the drop-down box, will put the JeoViewer in Pan mode. While in this mode, you can click on the map to indicate where the center point of the map image is to be placed. The map will be redrawn.

- **Point Query Mode:** indicated by the bold question mark (?). By pressing the icon or selecting “Point Query” in the drop-down box, will put the JeoViewer in Point Query mode. To use point query simply place your cursor over a location on the map you wish to query and click your left mouse button. A dialog box will be displayed listing the names of the objects within 10 pixels of the click point. (see Figure A12). Selecting one of the items in the Point Query list, enables the Zoom and Hi-Lite buttons on the Point Query Dialog. Pressing the “Hi-Lite” button cause the corresponding object on the map view to change color. In addition, pressing the “Zoom” button automatically zooms in at the location of the selected object. Selecting the Object within the List view, and then clicking the tab with the Table view, will show the attributes for the particular object (See Figure A13). These attributes are set to the values that are read in from the Facilities shapefile for the installation (values from the corresponding DBF file). Later, during the execution of the simulation, other attributes will be available to look at, such as the HVAC doors and window state and contamination status.

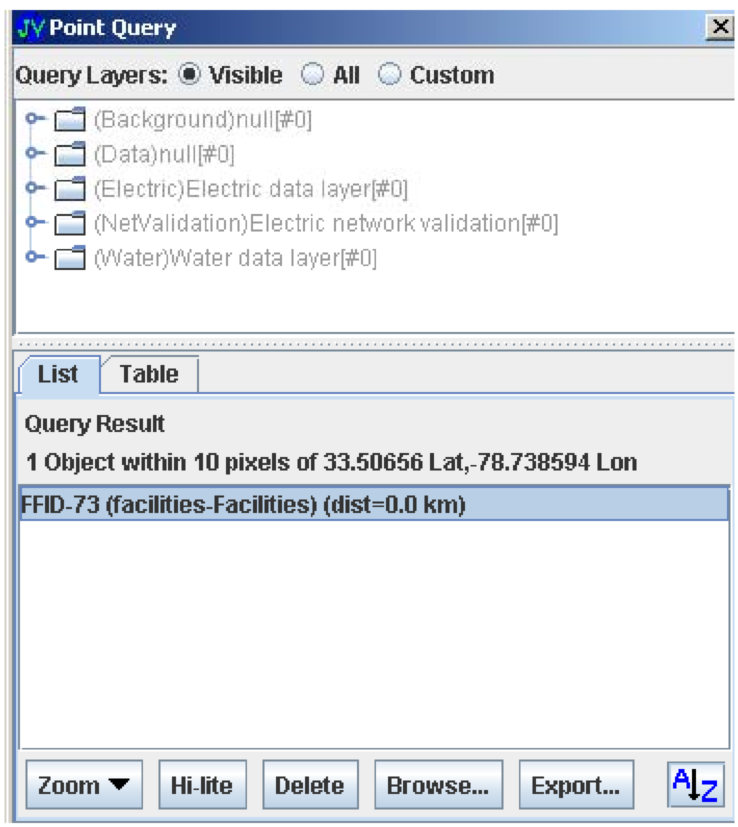


Figure A12. Point Query window after clicking on a building in the JeoViewer window.

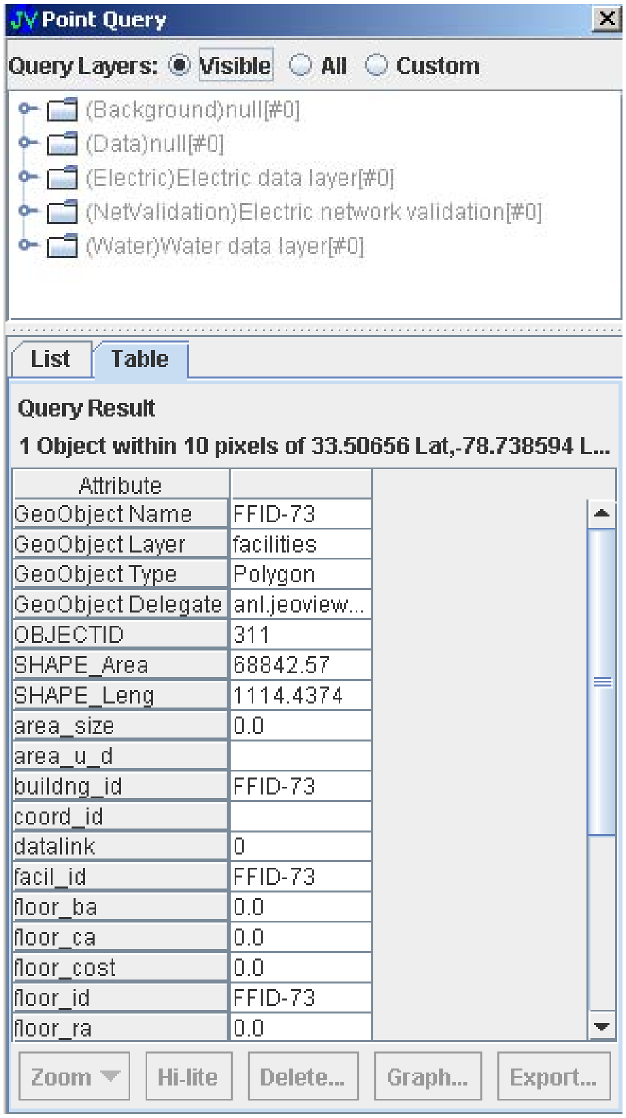


Figure A13. Point Query window, showing attributes in the table view

- **Box Query Mode:** indicated by the question mark in a box icon. Selecting this mode, you can use the rubber band box to indicate that you want to query everything within that box. The Query Dialog will list all objects within the indicated box within the List view (like in Figure A13).

- **Distance Tool:** indicated by the ruler icon. Selecting this mode, you can click on the map and a line-drawing tool will start drawing a line as you drag. At the bottom of the screen, in the Message area, the total distance will be shown each time you click. Double-click to end the distance calculation.

CBR Scenario Setup

JeoViewer modes that are specific to the CBR application are included on the Mode Tool Bar along with the default navigation modes (see Figure 14). To select any of these mode buttons (placing the cursor over the icons on the tool bar brings up a tool-tip with the label of the incident modes), click on the button. Then after selecting that mode, click the corresponding icon on the map, if one exists, in order to edit it, or click on a location on of the map to add a new release of that type at the location. The corresponding Incident Configuration window for the specific release comes up with the information for that release (see the following sections).

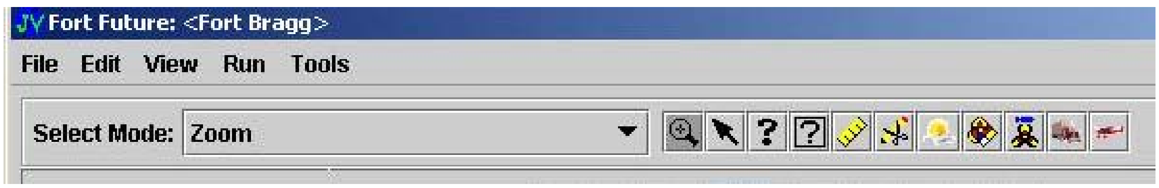
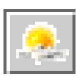


Figure A14. The Mode toolbar on the main JeoViewer window.



Atmospheric Data

Atmospheric data is necessary for the simulation to execute a CBR release. You may also add any number of CBR release incidents, but you need to only have a single meteorological event. If you forget to enter atmospheric data, a warning dialog will prompt you to do so if you try to run the simulation. There is a default atmospheric reading included with the delivered scenario. You can edit it with current parameters. To input atmospheric data, select the Atmospheric Data mode (either from the drop-down select mode menu or by clicking on the icon) and then move your cursor anywhere over the map and click the left mouse button or just click on the existing icon on the map. This brings up the Meteorology Input window (Figure A15).

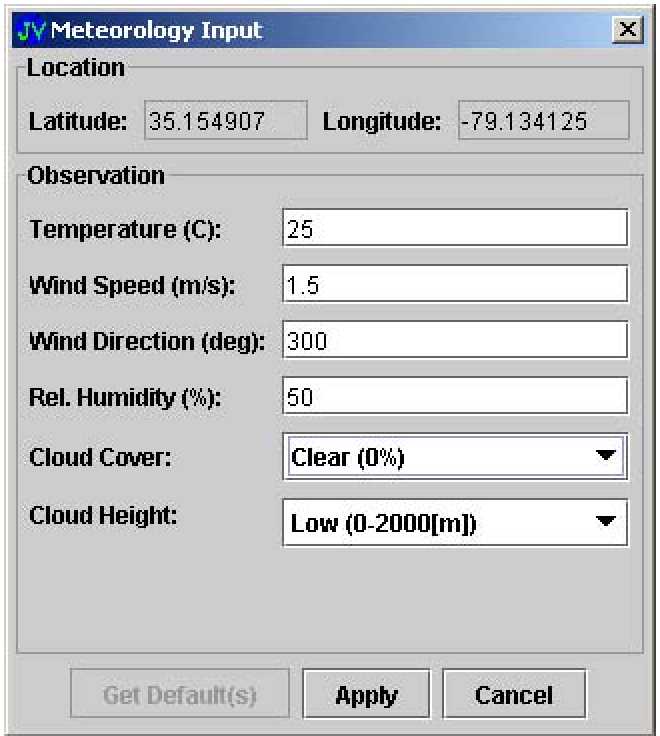


Figure A15. Meteorology Input window.

Enter data that will be used for all the releases in the simulation. This data will be used by the SEBMET model during the simulation run. Click Apply to save the data. Enter temperature (in Celsius), wind speed (m/s), wind direction (direction from which the wind comes from i.e. North Wind = 0 degrees, East = 90, South = 180, and West = 270), relative humidity (%).

The Cloud Cover drop-down box gives the selection of cloud cover, sometimes referred to as sky condition. The user can specify cloud cover in qualitative terms as outlined in Table A1. Table A1 also provides the corresponding three character codes as reported by automated weather stations (ASOS) as well as the fraction of sky obscured for the various classes.

Table A1. Cloud information, for use in SEBMET.

Cloud Amount	ASOS Code	Percentage of sky obscured
Clear	CLR	0%
Mostly Sunny	FEW	25%
Partly Cloudy	SCT	50%
Mostly Cloudy	BKN	75%
Overcast	OVC	100%

The second parameter describing cloud observations is ceiling height, which refers to the height above ground of the cloud base. The user can enter one of three qualitative ceiling height classes outlined in Table A2. Click Apply to save any changes.

Table A2. Cloud height categories, for use in SEBMET.

Qualitative Category	Ceiling Height Range [m]	Description
Low	0 – 2000	Dark, heavy appearance. Also can be puffy or broken as in cumulus or stratocumulus clouds. Sun not visible through clouded areas.
Mid Level	2000 – 5000	White, or light grey colored clouds, sometimes with ripples. Also can appear as bluish veil or layer of clouds with no detail, through which the sun may be dimly visible.
High	5000 – 15000	Thin wispy clouds or cloud layers. Sometimes associated with halos around the sun or moon. Sun and bright stars usually visible through these clouds.

CBR Incidents

The CBRSim allows the user to assign five different types of CBR release incidents:

- Chem/Bio Weapon Incident – Hazard Prediction and Assessment Capability (HPAC) Incidence Model*
- Chem/Bio Facility Incident - HPAC Incidence Model
- Radiological Weapon Incident - HPAC Incidence Model
- Industrial Chemical Transport Incident - Chemical Accident Stochastic Risk Assessment Model (CASRAM) Incidence Model
- Industrial Chemical Spray Incident - CASRAM Incidence Model

CBRSim allows the user to select more than one incident for a simulation. However, there is one caveat to running multiple releases during a simulation: you cannot have the same chemical released from an HPAC incident model and a CASRAM incident model during the same simulation run. For instance, if you select an ammonia release for the Chem/Bio Facility Incident you cannot select ammonia for an Industrial Chemical Transport Incident. If you have selected the same chemical for these, a conflict resolution window will appear that can be used to resolve the conflict (see running the simulation section below).

 Chem/Bio Weapon Incident

To enter information needed to run the CBRSim Chem/Bio Weapon Incident, either select the "Chem/Bio Weapon Incident" from the Select Mode: drop-down menu or click on the  icon. Then move your cursor over the point on the map where the release should be located and click the left mouse button. A confirmation dialog box will come up to verify that you want to create a new Incident at that location (Figure A16).

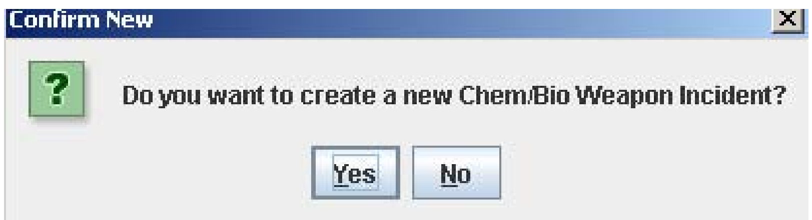


Figure A16. Confirmation dialog box for a new chem/bio weapon incident.

Select "Yes" in the confirmation dialog box to bring up the Incident Configuration Window (Figure A17).

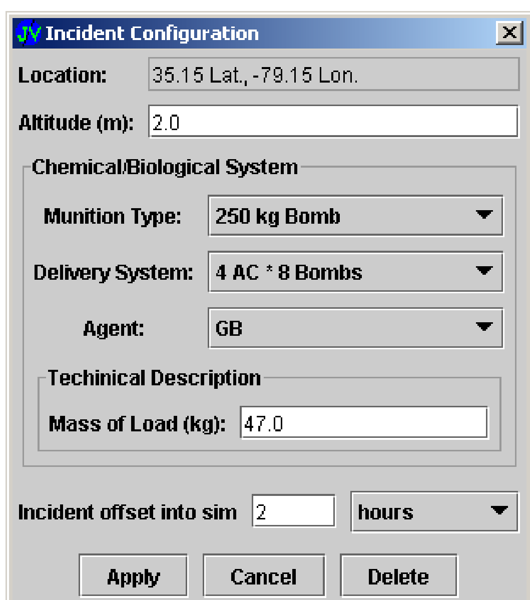


Figure A17. Incident configuration window for chem/bio weapon incident.

At this point, you may enter/edit any variables, cancel (which will close the window), or Delete the incident. Note that CBRSim application is automatically loaded with an example: CBWeapon release (for Sarin) already placed on the map (Figure A18).

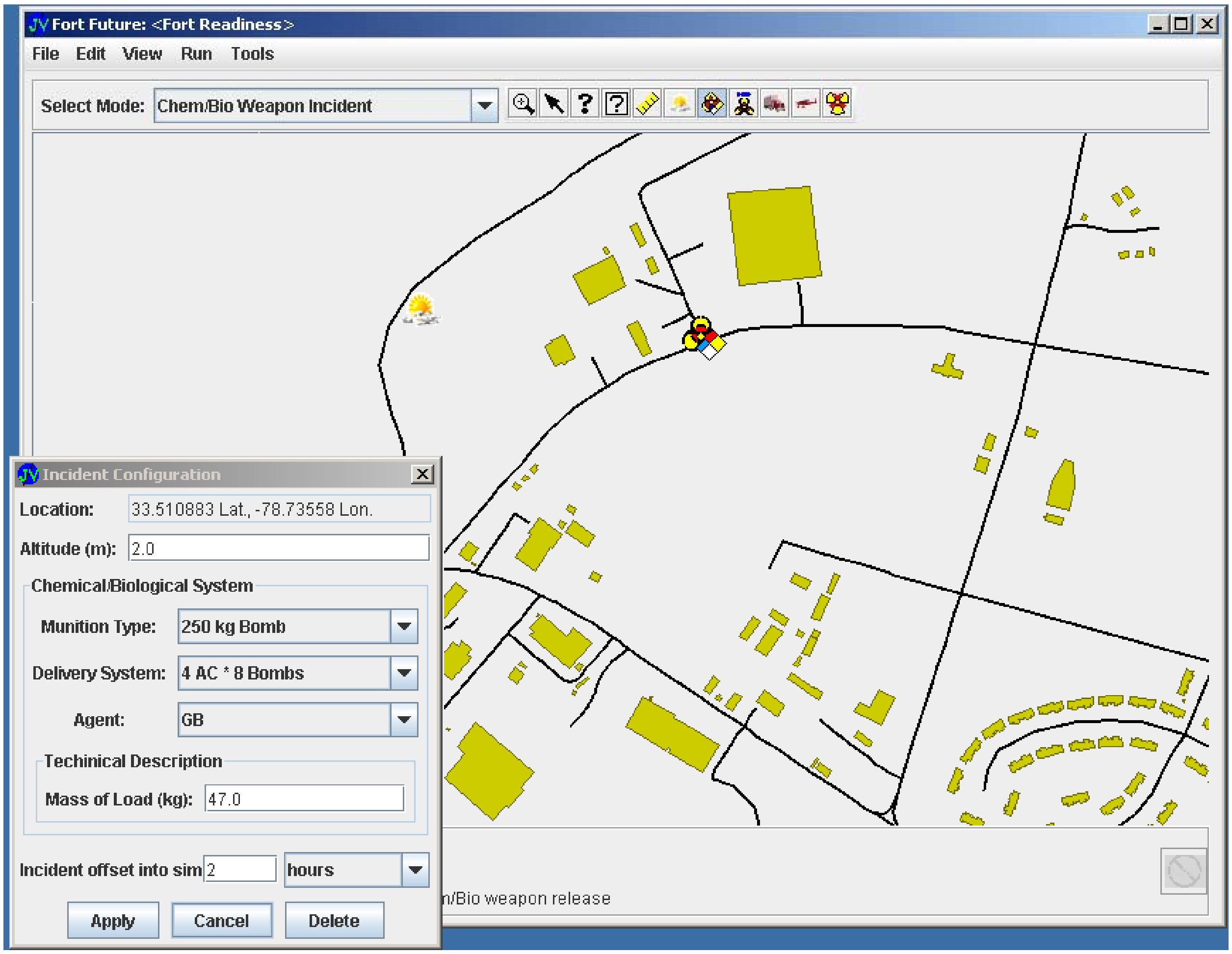


Figure A18. CBWeapon Sarin example incident loaded into CBRSim.

To edit the information entered in the pre-loaded example for Sarin release, select the Chem/Bio Weapon Incident mode icon () and then click the corresponding icon on the map (Figure A18). Information about this release can then be edited, or the release can be deleted. The icon will be removed from the map, showing that it is deleted.

Referring to Figure A18, at this point, you may enter/edit any variables, cancel (which will close the window), or Delete the incident. The Latitude and Longitude will be filled in for you from the location you clicked on the map. Altitude is editable, and refers to the height at which the weapon will explode and release its agent. The value is in meters. At the bottom of the window, you can choose how many hours offset into the simulation this release is to occur.

The middle section of the window is where the user defines the HPAC-CBWeapon-specific parameters. There are pre-defined Munition Types in the drop-down box that set default parameters based upon expert opinion and experiments in the field. After selecting a munition type, the Delivery System drop-down box will fill with relevant values for that munition type. The agent needs to be chosen from the available agents that are usually contained within the chosen weapon delivery system. Refer to the HPAC User's Manual for a detailed description of the relation of munition types, delivery systems, and agent.

Lastly, under the Technical Description section, the only parameter that CBRSim allows the user to edit is the Mass of Load (kg). This is the agent payload of the munitions. The rest of the parameters that are editable within HPAC are set to the defaults for simplicity in CBRSim setup.

 Chem/Bio Facility Incident

To enter information needed to run the CBRSim Chem/Bio Facility Incident, either select the "Chem/Bio Facility Incident" from the Select Mode: drop-down menu or click on the  icon. Then move your cursor over the point on the map where the release should be located and click the left mouse button. A confirmation dialog box will come up to verify that you want to create a new Incident at that location. Select "Yes" in the confirmation dialog box to bring up the Incident Configuration Window (Figure A19).

At this point, you may enter/edit any variables, cancel (which will close the window), or delete the incident. The Latitude and Longitude will be filled in from the location you clicked upon the map. Altitude is grayed out since this incident model assumes the release is near the ground at a facility. At the bottom of the window, you can choose how many hours offset into the simulation this release is to occur.

The CBFacility-specific values are shown in the middle section of the window. The Model Type refers to the HPAC options for this incident model. The default one, Damage Category, is the only one offered through

CBRSim as it is the easiest to use. So, that drop-down box has no other selections available at this time.

The Damage Category severity drop-down box lets the user chose between Light, Moderate, Severe, or Total severity of damage done to the target. Next, the agent is chosen from the list of available agents within CBRSim. The last piece of information that is needed is the mass (in kg) of the agent that is contained within the target. It is assumed that the target of the attack is an agent within a confined container within the facility. These parameters are used within the HPAC CBFAC incident model and when the simulation is run, it will calculate the amount of viable agent released from the type of severity selected. These values are not shown in the interface, but are passed into the HPAC SCIPUFF model.

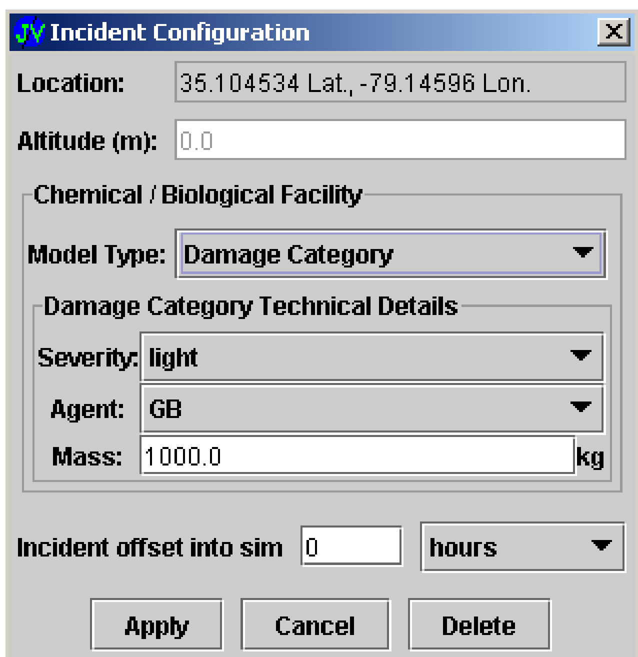


Figure A19. Incident Configuration Window for chem/bio facility incident.

 Radiological Weapon Incident

To enter information needed to run the Radiological Weapon Incident, either select the "Radiological Weapon Incident" from the Select Mode: drop-down menu or click on the  icon. Then move your cursor over the point on the map where the release should be located and click the left mouse button. A confirmation dialog box will come up to verify that you want to create a new Incident at that location. Select "Yes" in the confirmation dialog box to bring up the Incident Configuration Window (see Figure A20). At this point, you may enter/edit any variables, cancel (which will close the window), or delete the incident. Like the other incident screens, the Latitude and Longitude will be filled in from the click location on the map. The Altitude is grayed out and assumed to be on the ground. At the bottom of the window, you can choose how many hours offset into the simulation this release is to occur.

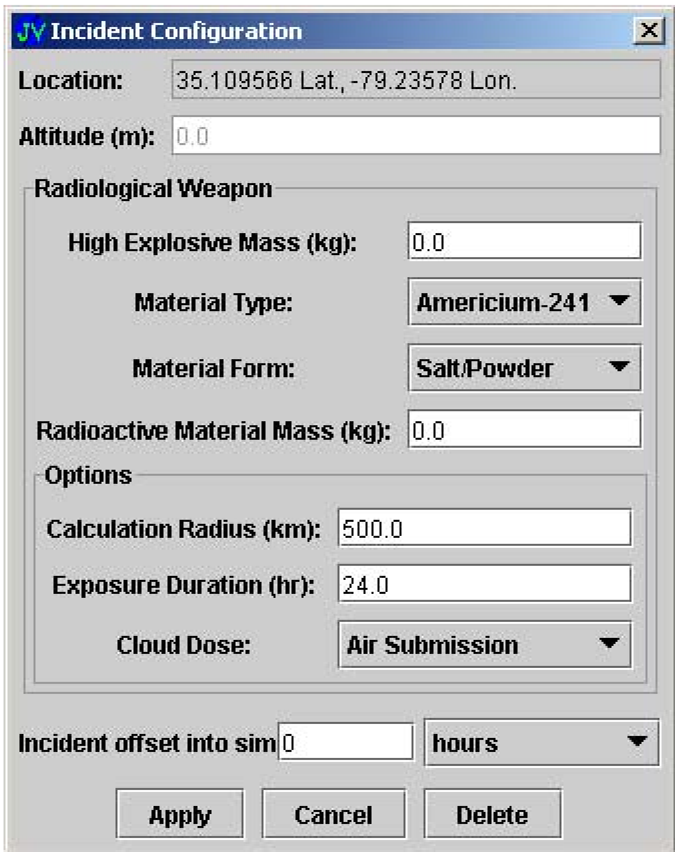


Figure A20. Incident Configuration window for radiological weapon incident.

Figure A20 shows the default incidence characterization window for a radiological weapon incident. The middle section defines the HPAC-RWPN-specific parameters for an explosive Radiological Dispersal Device (RDD), which is assumed as the source of the radioactive material. The "High Explosive Mass" field must be entered by the user. This field is automatically filled in with a default of 0, but the user must make sure to give it a valid weight (in kg.) The default "Material Type" is set to Americium-241 and the "Material Form" is default to Salt/Powder. The user may select from a list of 18 available radioactive materials. The drop-down box for material forms fills in with the appropriate values for the Material Type chosen. The radioactive material mass must also be entered. This field is the amount (in kg) of the actual radioactive material within the RDD. There are three options that are also needed, “Calculation Radius, Exposure Duration, and Cloud Dose. The calculation radius refers to the effective range of the incident. The default value is 500 km. Exposure duration is the time that the exposure occurs. Default value is 24 hours. Lastly, the cloud dose option choices are “Cloud Shine” and “Air Submersion.” Air Submersion is the default, and is a faster, but less accurate calculation.

After editing all the variables, press Apply to save the data and create the incident. After the Apply button is clicked, a corresponding icon () is shown on the map at the location that was clicked.

 Industrial Chemical Transport Incident

To enter information needed to run the CASRAM-specific Industrial Chemical Transport Incident, either select the “Industrial Chemical Incident” from the Select Mode: drop-down menu or click on the truck () icon. Then move your cursor over the point on the map where the release should be located, and click the left mouse button. A confirmation dialog box will come up to verify that you want to create a new Incident at that location. Select “Yes” in the confirmation dialog box to bring up the Incident Configuration Window (Figure A21).

At this point, you may Enter/Edit any variables, Cancel (which will close the window), or Delete the incident. The Latitude and Longitude will be filled in from the location you clicked upon the map. Altitude is grayed out, since this incident model assumes the release is near the ground at a facility. At the bottom of the window, you can choose how many hours offset into the simulation this release is to occur.

The user then picks the type of chemical that is being transported. The middle section defines the type of container the agent is being transported within, as well as its capacity (See Table A3 for the types of containers that can be chosen, along with the typical size). If the container type is Drums or Cylinders, the window will change to enter the number of containers. Otherwise, if a type of Tank or Truck is the chosen container, the window shows fields for entering the size of the hole where the container has been breached and is spilling the contents, and the location of the hole within the container. Circular holes are the assumed shape, and the hole size is defined by the diameter. For "worst case" incidents use 100 cm. The location of the hole in the container is important, since it limits the amount of the material escaping from the container, and influences the flow rate of liquids from the hole. This is given as the percentage of container height, as estimated from bottom to where the hole is located. (Bottom is 0, top is 100.) For "worst case" incidents, use 0 (hole at bottom).

The Surface Type drop-down box is the type of surface upon which the agent is spilling. Selections are Natural (meaning ground, terrain), Asphalt, and Concrete.

Lastly, the Default Pool Depth is the default selection for estimating the size of the pooling chemical on the ground. If you have an indication of the actual size of the pool, for example, a diked region around tanks in a tank farm, select Pool Area (m^2), and then type in the squared area's value in the text field, next to the drop-down box. The user may also select Equilibrium Depth (for free-standing pools that spread without restriction) and enter the value in millimeters in the text box.

Table A3. Container types for industrial chemical transport incident model.

Container Type	Notes	Typical Size
111A Tank Car	Std rail car for hazardous liquid materials	20000 gal.
105; 112 Tank car	Std rail car for hazardous materials under pressure	20000 gal.
MC306 Tank Truck	Highway cargo tank for flammable liquids	6000 gal.
MC307 Tank Truck	Highway cargo tank for flammable liquids, weak acids and wastes	6000 gal.
MC312 Tank Truck	Highway cargo tank for toxic liquids and acids	4000 gal.
MC331 Tank Truck	Highway cargo tank for hazardous materials under pressure	8000 gal.
Drums	Package freight: 5-200 gallon drums	55 gal.
Cylinders	Package freight 1-100 gallon cylinders	19 gal.

Use MC312 and MC331 for highway liquids and gases. Note that this parameter currently has little influence on the results, except for Drum and Cylinder containers (all of the agent within Drum and Cylinder containers is assumed to be released).

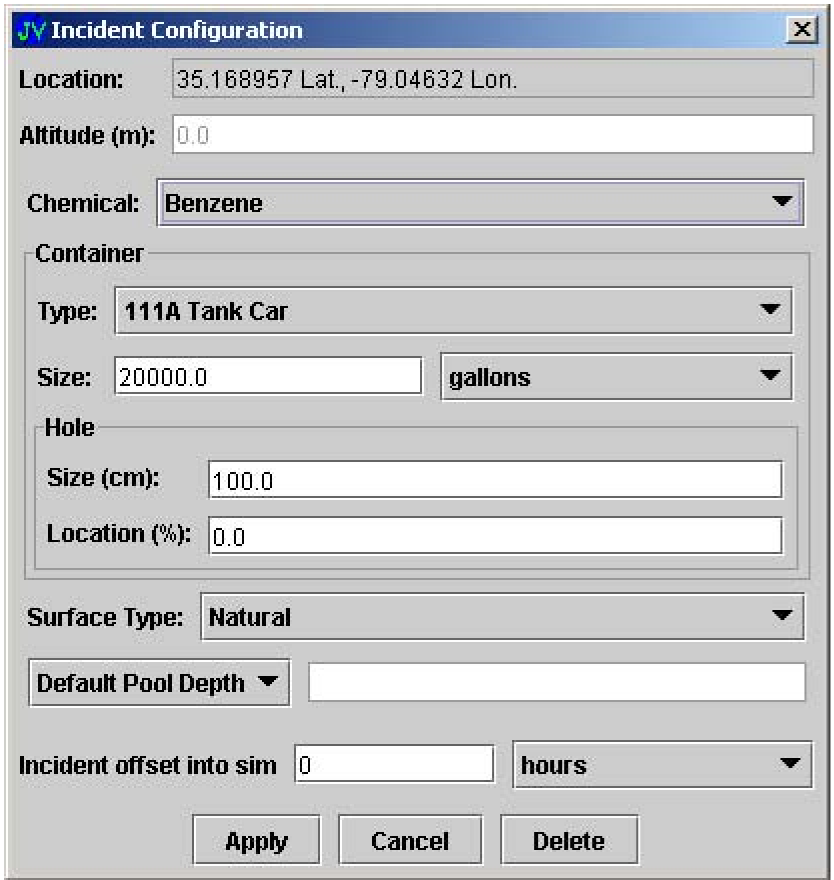


Figure A21. Incident Configuration window for industrial chemical transport incident.

Figure A21 shows a release of Benzene from an 111A Tank Car (the user may select from a long list of available chemicals). The size of the Container is 20,000 gallons (container size can also be provided in kg or pounds), and the hole size is 100 cm located at the bottom of the container (% from the bottom: 0% = bottom hole, 100% = hole on top). Leaving a Default Pool Depth will let CASRAM choose what is appropriate for the particular release. The incident will occur at the 0-hour mark in the simulation run (unless set by the user to start some time (in days, months, milliseconds, seconds, weeks, years, hours, or minutes) after the simulation starts . After editing all the variables, press Apply to save the data and create the incident. After the Apply button is clicked, a corresponding icon () is shown on the map at the location that was clicked.

 Industrial Chemical Spray Incident

To enter information needed to run the Industrial Chemical Spray Incident, either select the “Industrial Chemical Spray Incident” from the Select

Mode: drop-down menu or click on the airplane () icon. Then move your cursor over the point on the map where the release should be located and click the left mouse button. A confirmation dialog box will come up to verify that you want to create a new Incident at that location. Select "Yes" in the confirmation dialog box to bring up the Incident Configuration Window (Figure A22). At this point, you may enter/edit any variables, cancel (which will close the window), or delete the incident. . The Latitude and Longitude will be filled in from the location you clicked upon the map. Altitude of the spray release needs to be entered. It is assumed that the agent is being dispersed from a plane. At the bottom of the window, you can choose how many hours offset into the simulation this release is to occur.

Next, choose the Chemical being sprayed from the airplane from the drop-down list. The release rate needs to be input in mass per second (either kg or pounds). The release duration is the duration of the spray release in seconds. Lastly, the speed (km / hour) and heading of the plane need to be entered for calculating the end points of the linear release for the dispersion model. After entering the data, click Apply to save the data.

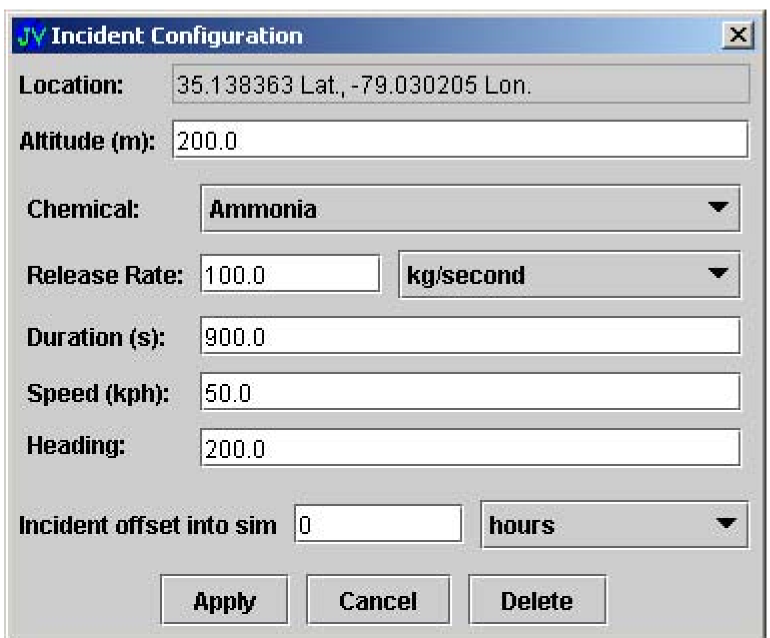


Figure A22. Incident Configuration window for industrial chemical spray release.

Figure A22 shows an example values for a Chemical Spray Release incident. The altitude (in meters) is 200.0. Ammonia is the selected chemical (several other chemicals are available in the drop-down menu). This ammonia is released at a rate of 100.0 kg/second (the user can also provide rates in pounds/second) for a duration of 900 seconds at a speed of 50 kph and heading 200.0 (compass heading). This release is not offset into the simulation (offset set to 0), meaning the release will start at the beginning of the simulation.

Running the CBR Simulation

After the user has entered all incident information, the CBR Simulation is ready to run. To run the simulation, select “Start Simulation” from the Run drop-down menu (Figure A23).

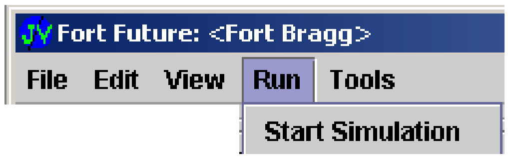


Figure A23. "Start Simulation" option on the "Run" drop-down menu.

Selecting the “Start Simulation” option will bring up the “Simulation Manager Window” (Figure A24).

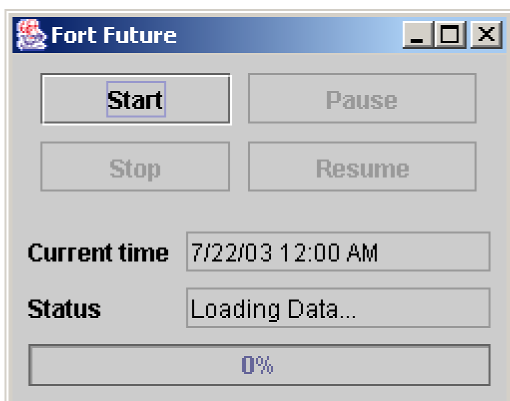


Figure A24. The Simulation Manager window.

Resolving Data Conflicts

There is only one caveat to running multiple releases during a simulation: You cannot have the same chemical released from both an HPAC incident model, and a CASRAM incident model, during the same simulation run. If this happens, a Release Conflict window will appear when you click “Start,” which allows you to resolve the conflict before running (Figure A25).

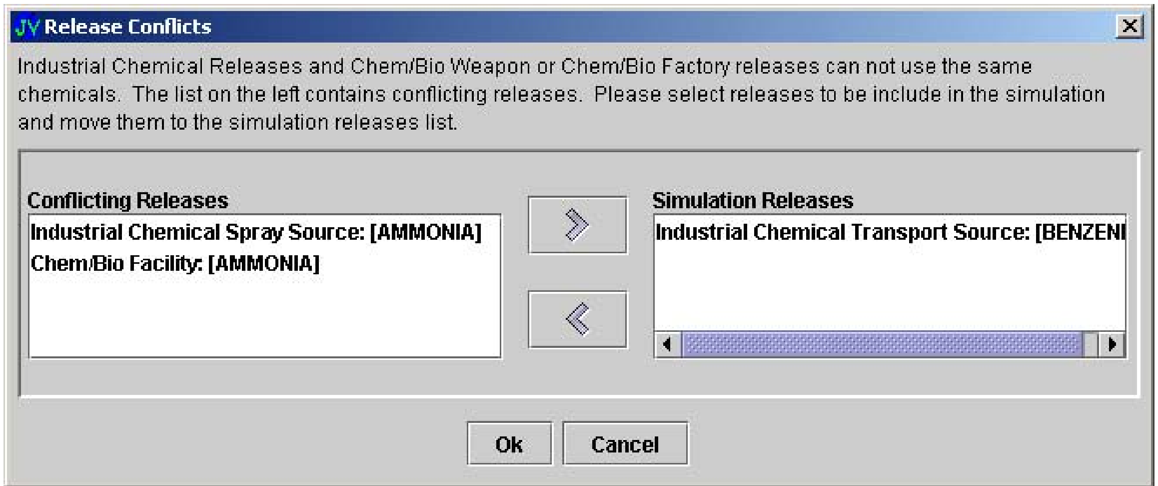


Figure A25. The Release Conflicts window, showing the conflicting ammonia releases.

Following the instructions on the window, select which of the Ammonia releases you want to use for the simulation. Figure A26 shows the result of selecting the Spray release and clicking the right-arrow button, indicating that is the release you would like to run, using Ammonia.

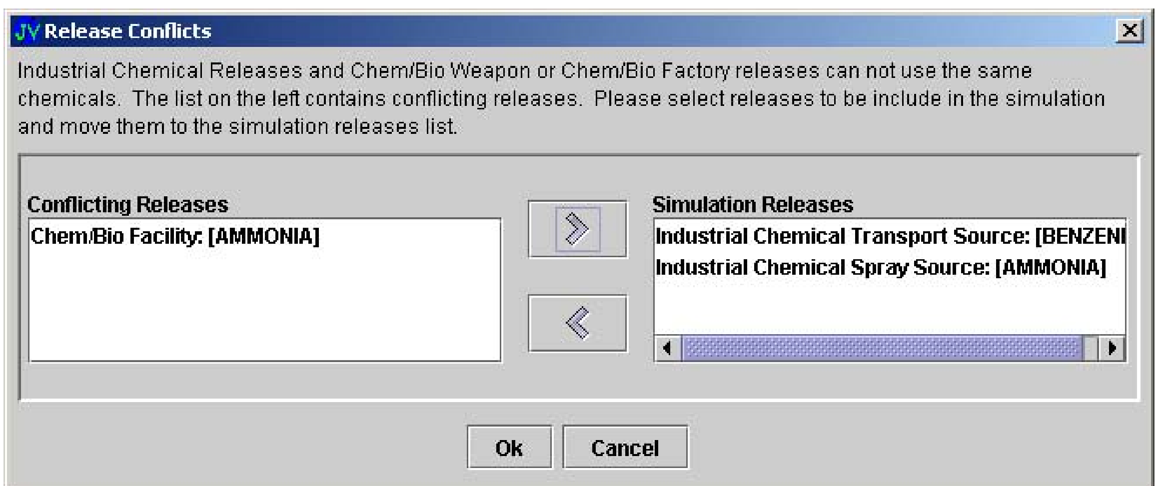


Figure A26. The Release Conflicts window, showing the selected releases.

After resolving the conflicts, press “OK” button and the “Simulation Manager Window” will come up (Figure A24).

CBR Simulation

Press the “Start” in the Simulation Manager Window (Figure A24) to start up the simulation. When a simulation is started, all selected incident models are executed. Also, the Meteorological data will be converted to an HPAC-readable format after being processed by SEBMET so that both

CASRAM and HPAC/SCIPUFF will be working off of the same meteorological data set. Source data generated by the incident models are passed onto the Second-order Closure Integrated PUFF (SCIPUFF) air dispersion model within the HPAC software package to generate results.

The “Simulation Manager Window” (Figure A24) provides information on the status of the simulation and allows the user to “Pause”, “Resume”, and “Stop” the simulation. At any time during the simulation, you can Pause the simulation (in case you want to query anything on the map), but you cannot make any changes to the release parameters once the simulation has been started. To continue running the simulation, click the “Resume” button.

The progress of the simulation is shown in the progress bar at the bottom of the “Simulation Manager Window,” along with the current simulation timestamp. After the simulation terminates, or after you press “Stop,” the “Start” button will be re-enabled. At this point, you can restart the current simulation (with the release parameters reset to the beginning). If you want to edit the parameters, or add/remove releases, you must close the “Simulation Manager Window.” Then, you can make your edits by clicking modes on the Tool Bar and editing the Incident Data windows. Then, when you are ready to run again, select the “Start Simulation” option in the “Run” drop-down menu.

Viewing CBR Results While the Simulation Executes

After the simulation starts up, the SCIPUFF is run every 15-minutes of simulation time and produces plots of surface dosage, surface deposition, and concentration for each time step.

You can bring up the Thematic Legend by selecting the View->Show Thematic Legend menu item. This legend will show both the facility concentration levels and the selected Plume plot values. Figure 27 shows the JeoViewer window with the thematic legend and a Sarin 15-minute concentration plot. The legend is showing the concentration values for the contours in the lower half (Sarin Plumes) and in the upper half, its showing the indoor concentration values calculated by the leaky box model. The facilities are colored according to the level of indoor concentration by default.

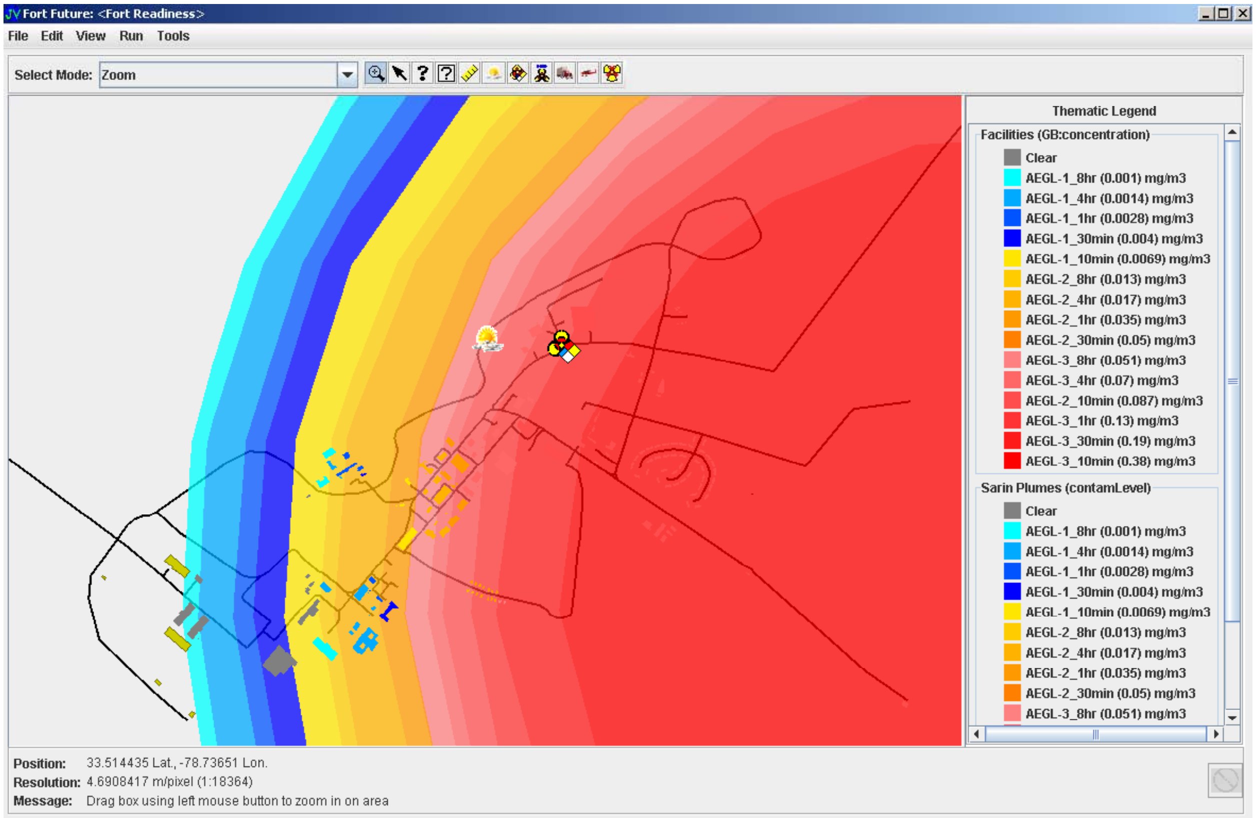


Figure A27. Main JeoViewer window, showing a concentration plot for Sarin, and showing the Thematic Legend.

During a simulation, the default is to show concentration plots for the first material/chemical release selected. Note that only one release material/chemical and one plot type can be displayed at one time. To change which material/chemical or plot type is displayed, see information on “Display Control” explained in the “Menu Items – Tools Menu” section above.

As mentioned previously, turning off the Aerial photo lets you see the display more clearly. Plot Types that can be selected for display are Surface Dosage, Surface Deposition, and Concentration. To display the results of a different material/chemical release, select it from the Material / Chemical section of the “Display Control” window. When alternative materials/chemicals and plot types are selected, the display and the thematic legend update accordingly. Often, there may not be any discernable plots on the map due to the fact that the concentration values are less than the minimum contour level. In that case, you will not see anything displayed when selecting that plot type. Figure A28 shows the Display Control window during the execution of the simulation.

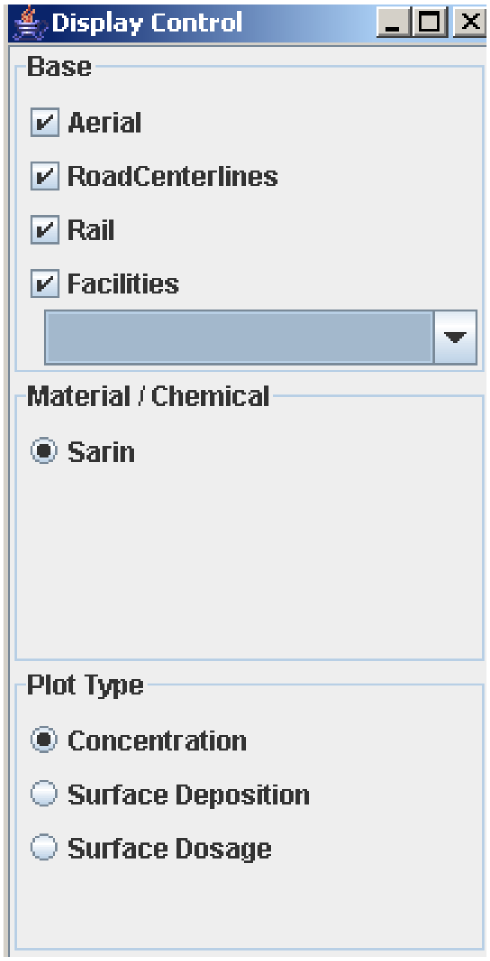


Figure A28. The Display Control window, showing the selections available to view during simulation execution.

Occasionally, there are very small values for a released material/chemical. In these cases, the Thematic Legend will be initialized with only two contour levels. This may cause the entire region to display as red (the "lowest" value) due to the fact that every value may be extremely small. This is an artifact of the way HPAC/SCIPUFF is run within CBRSim.

While the simulation is executing, you can zoom, pan, and select plot displays from the JeoViewer navigation tools, as well as Pause, Resume, or Stop the simulation from the Simulation Control window. The SCIPUFF model is being called every 15 simulation minutes, and the display is updated with each time step. At the end of the simulation time, the Simulation Manager Window will re-enable the Start button and the status will be shown as terminated.

Leaky Box Modeling

In addition to CBR air dispersion modeling, the CBRSim application also includes a Leaky Box Model that models the indoor concentration levels for each facility and for each material/chemical released in the CBR incident models. The Leaky Box model automatically runs and uses concentration data generated by the SCIPUFF model and building data that has been uploaded with the facility data as inputs.

Output from the Leaky Box Model results are displayed visually in the CBRSim Main JeoViewer Window. Facility outlines are assigned colors based on their concentration level. The Thematic Legend will automatically display a legend for the facility concentrations. Even though you may be viewing plots of different types (surface dosage or surface deposition), only concentrations are calculated for facilities. When the user selects a different material/chemical using the “Control Display” window, the facilities display will automatically change to reflect the concentrations of the new material/chemical. The Thematic Legend will also be updated to display the legend for the new material/chemical. By keeping the Facilities drop-down box in its default choice (blank), the facility concentration will continue to be displayed.

Exiting CBRSim

To quit the system, select File->Exit. Exiting the CBRSim client gets rid of the main Java process, but the associated DOS window remains active. It will read “Press any key to continue...” Just close the window. Since ICE/HPAC, the HPAC Model Controller, and the CORBA naming server are all separate processes with their own DOS windows, you will need to close each of the windows when you are ready to exit. Otherwise, you should not restart the CBRSim application because it will try to start up all the processes again. (Don’t forget to close the tnameserver window, it may be minimized in the Task bar.)

CBRSim Directory and File Structure

The CBRSim installer includes a fictional Fort Readiness. The FFVI install directory contains the needed files for creation of the JeoViewer layers and definition files as well as the DOS bat scripts and executables for the installation-specific simulation. If you installed in the default directory, for example, c:\Program Files\FFVI_Readiness, all the files needed for that installation's simulation is within that directory hierarchy. The shortcut created on the desktop points to this directory and the fortfuture.bat file. Here is a synopsis of the files you'll find there:

- Top-level dir: fortfuture.bat file and HPAC.bat file along with the desktop shortcut and FF icon. These are the only relevant files in this directory.

props – Java property files needed by the CBRSim application

- mtlFiles.zip – this file contains the edited HPAC material file directory needed for CBRSim. Argonne added chemicals that were not included in HPAC, but were modeled in CASRAM and edited existing material files for use in CBRSim. The installation script unzipped this file automatically in the HPAC4\server\data\materials directory after zipping up the original files that got installed with HPAC.

- CamStudio – this directory contains the open source CamStudio software. The Recorder.exe is called from the CBRSim main window when choosing Run->Run Snapshot Recorder. The Player.exe is used for playback of a recorded session.
    - GeoData
        - readiness.dat – this is the JeoViewer frame definition file. This file describes the JeoViewer layer definition files and also describes the Projection that the JV uses to load the installation shapefiles. The topological data for the installation is expected to be named lfhypgd_five_foot.shp (and its attending other files), and the Projection is expected to be:
        - PROJCS["NAD_1983_UTM_Zone_13N",
        - GEOGCS["GCS_North_American_1983",
        - DATUM["D_North_American_1983",

    - SPHEROID["GRS_1980",6378137.0,298.257222101]]
,
    - PRIMEM["Greenwich",0.0],
    - UNIT["Degree",0.0174532925199433]],
    - PROJECTION["Transverse_Mercator"],
    - PARAMETER["False_Easting",1640416.666666667],
    - PARAMETER["False_Northing",0.0],
    - PARAMETER["Central_Meridian",-105.0],
    - PARAMETER["Scale_Factor",0.9996],
    - PARAMETER["Latitude_Of_Origin",0.0],
    - UNIT["Foot_US",0.3048006096012192]]

- CASRAM – directory for the Fortran programs CASRAM and SEBMET and their associated data files.
- jar – directory containing all the Java jar files for running CBRSim
- jre – directory containing the Java 1.5 runtime executable. By installing the jre along with the installation data, the user does not have to do a system install of Java nor have to affect any version he may have already installed on his computer. The CBRSim will use this jre for executing.
- lib – directory containing the native libraries needed for CBRSim (whereas the FFVI can run on multiple Operating Systems (linux, windows, and mac os x), the HPAC model is only available for Windows systems.
- Locations\Readiness (or FtCarson) – this directory contains the data files for the JeoViewer (GeoData) and for initializing the process model (ScenarioData). The file names between the 2 installations

are identical. To create Fort Carson, the Fort Readiness is used as a template and the files copied to the Locations directory of the new installation. The file names remain the same, but the contents of the following files may be edited to create the site-specific information used in the simulation:

- GeoData
    - readiness.dat – this is the JeoViewer frame definition file. This file describes the JeoViewer layer definition files and also describes the Projection that the JV uses to load the installation shapefiles.
    - layer_defs – this directory holds the layer definition files pointed to from the readiness.dat file: Background.def is the main file which describes all the layers and the styles for displaying the data in the JV.
    - boundary – this directory holds the ESRI shapefiles for the installation boundary
    - facilities – this directory holds the ESRI shapefiles for the building footprints for the installation. The names of the HVAC fields to be included in the file for important buildings are:
        - HVACField fieleName=”EXCH_HVAC” default=”2.0”
        - LeakageOpenField fieldname=”EXCH_HVAC” default=”2.0”
        - LeakageClosedField filename=”EXCH_HVAC” default=”.5”
    - network – holds the ESRI shapefiles for the installation road network
- ScenarioData

- DB – this directory contains the optional personnel, vehicle, and/or equipment files. These comma-separated files are used to initialize the attributes of the agents that will be modeled within the Process Model. Personnel in the case of CBRSim will be doing their daily work, and will react by sheltering-in-place during a contamination event.

- testdb3.xml – this is the user-editable scenario setup file written in eXtensible Markup Language (XML). The corresponding scenario.dtd file is used to validate the XML. This file is used to define the actions and reactive plans that the agents will be using (in this case to shelter-in-place) as well as the holding the time frame of the simulation run, the filenames of the road network and facility shapefiles, and default HVAC values for the buildings. It is optional to run the process model and it is disabled for Fort Readiness, but enabled for Fort Carson. The default time frame is Jan 1, 2020 to Jan 3, 2020.

- ContourColors.xml (.dtd) – these files define the contour colors shown within the thematic legend. There is no need to have to edit these files.

At a minimum, the building shapefile and road network shapefiles are needed for the CBRSim simulation. Other installation-specific ESRI shapefiles can be imported and shown in the JeoViewer, but are not used in the simulation part of the system. If other types of files are to be imported, the GeoData\readiness.dat file can be edited to define a Shapefile Loader and the projection that it's in, as well as a reference to the file location. Then a layer and style need to be defined in the Background.def file for rendering it in the JeoViewer. The editing of these files is beyond the scope of this document.

Appendix B: Building Air Change Rate Estimates for CBR Analysis

Note: The following text is extracted from draft Letter Report entitled *Building Air Change Rate Estimates for CBR Analysis,* written by Andrew Persily, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg MD dated 15 September 2008, to ERDC-CERL.

Introduction

Building air change rates impact energy consumption for space conditioning and indoor contaminant levels in relation to general indoor air quality issues as well as occupant exposure to airborne chemical, biological and radiological (CBR) agents. With respect to contaminant levels, air change rates impact both the entry and subsequent dilution of agents with outdoor sources and the dilution of those released internally.

The air change rate of a particular building at a given time is a function of building layout, HVAC system design and operation, the operation of other building systems such as exhaust fans and vented combustion equipment, building envelope airtightness, exterior weather conditions, and occupant actions, e.g. window and door opening. These dependencies can lead to 10-to-1 or even larger variations in the air change rate of a given building, and even larger variations between buildings.

The most reliable means of determining a building's air change rate under specific conditions is to measure it with a tracer gas technique. Other measurement methods exist, but they are do not necessarily characterize all of the relevant airflows (i.e. outdoor air intake traverses that don't account for envelope infiltration, or are often associated with higher levels of measurement uncertainty. However, such measurements would need to be repeated under a range of conditions to generate a complete understanding of the building's air change rates for all situations of interest. Alternatively, modeling approaches exist that can predict these rates with an acceptable level of accuracy, assuming the required input data has been determined for the building of interest (ASHRAE 2005).

However, measurement and modeling is not always an option in a given building, and generic values may be more useful that building-specific rates to support certain types of analyses. Since such estimates are not building specific, they are associated with some level of uncertainty, but they are still useful as long as their approximate nature is understood.

This note presents air change rate estimates for a number of different building types: offices, homes, schools (including child development centers), barracks, multi-family residential buildings, retail buildings, restaurants, theaters, hospitals, gymnasiums, warehouses, and commissaries. These rates can be used to specify building air change rates for buildings that are included in the CBRSim Model.

A table is presented for each building type, based on design requirements in ASHRAE Standard 62.1 or 62.2, as appropriate (ASHRAE 2007a and 2007b), the limited measurements available (which do not exist for some building types), and engineering judgment.

In each building type table, the air change rate values are color coded to indicate the associated level of confidence. Air change rates based on design values or field measurements are shown in black, and are associated with an uncertainty of about 25%, though in some cases the uncertainty could be larger. Those shown in blue are based on very limited measurements or design considerations, and are noted to have an uncertainty of roughly 50%. The values in red are noted as being very speculative, and are associated with an uncertainty of 100%. These uncertainty values are all approximate, and in some cases, quite large due to the limited number of field studies that have taken place, and the building, weather, and system operation impacts on air change rates.

The user should be aware that without building and condition specific measurements, air change rates estimates are inherently approximate, but can still be useful for certain analyses.

Air change rates for building types

Offices

Table B1. Office building air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation Only				
Standard 62.1 minimum rate	0.75			
Standard 62.1, under ventilation	0.38			
Standard 62.1, over ventilation	1.13			
Economizer operation	3 to 5			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		0.75	0.9	1.1
Average tightness		0.9	1.1	1.5
Very leaky		1.1	1.5	2.0
Mechanical combined with open windows		1.5	2.5	3.5
EPA BASE study				
All data – mean (S.D.)	1.8 (2.1)			
Minimum outdoor air – mean (S.D.)	0.5 (0.4)			

Based on measured or design values, +/- 25%

Based on limited measured or design values, +/- 50%

Very speculative, at least +/- 100%

Table B1 presents the air change rate values for office buildings. These values fall into several categories, the first three being mechanical ventilation, infiltration and open windows. In each of these cases, the air change rates are associated with only that mechanism in effect. The Standard 62.1 minimum rate corresponds to roughly 10 L/s (20 cfm) per person of outdoor air ventilation, five occupants per 100 m^2 of floor area and a 2.4 m (7.9 ft) ceiling heights.* Other ventilation rates, occupant densities, and ceiling heights correspond to different air change rates per the following formula:

* The standard expresses area in terms of thousands of square feet (1,000 ft^2).

$$\text{Air change rate} = 0.036\ Q\ N / H$$

where:

Q = outdoor air ventilation rate per person in L/s,
N = number of occupants per 100 m^2 of floor area
H = ceiling height in m.

The next two entries in the table under the Standard 62.1 category, under ventilation and over ventilation, correspond to a 50% decrease and a 50% increase in the Standard 62.1 air change rate. Given the realities of system operation and maintenance, outdoor air intake rates often deviate from their design values. A 50% deviation is not unreasonable, based on the results of existing field studies (Persily and Gorfain 2004).

A third condition is included under mechanical ventilation, which is a range of rates under economizer operation in which the outdoor air intake fraction is increased to cool the building, as an energy savings measure, relative to using mechanical cooling equipment. Not all buildings are equipped with an economizer cycle, but those that do have air change rates in the noted range.

However, the rates in a particular building depend on the system design and operation, as well as the outdoor air temperature, which can lead to lower air change rates when it is colder outside. Also, note that a specific building may or may not have been designed to comply with Standard 62.1-2007, but rather with an earlier version, some of which had outdoor air requirements as low as 2.5 L/s (5 cfm) per person in office space.

The three cases for infiltration-only correspond to three generic levels of building tightness, and include a generic dependence on weather, from calm to severe. These characterizations of building tightness and weather are inherently approximate, and are not based on any specific numerical values or simulations. Therefore, the air change rates are noted as less certain than the design-based values. The open-windows values are even more approximate than the infiltration-only cases, as they ignore the wide variation in window opening patterns that might occur in a given building, and because of the lack of measurements of office building air change rates under these conditions.

Additional values are included for mechanical ventilation, in combination with envelope infiltration, for three levels of building tightness and three levels of weather. An additional set of values is included for mechanical ventilation in combination with open windows and three levels of weather.

The final two rows of the table present the mean air change rate (and the standard deviation) from the Environmental Protection Agency (EPA) Building Assessment Survey and Evaluation (BASE) study (Persily and Gorfain 2004). The BASE study was conducted in a random sample of 100 office buildings across the United States, and the values in the table correspond to the measurements made in the spaces involved in the study. The first of the two rows is based on all these data, while the last row includes only measurements conducted under minimum outdoor air intake.

Homes

Table B2 presents the air change rate values for single family homes. The first set of entries correspond to mechanically ventilated buildings in which a mechanical system brings outdoor air into the home. Note however that very few single family homes in the U.S., even new ones, use mechanical systems for outdoor air ventilation. These first three entries present the ventilation requirements in ASHRAE Standard 62.2, which depend on house size and number of bedrooms per the following equation:

$$\text{Air change rate} = 3.6\ [0.05\ A_f + 3.5\ (n_b + 1) + 0.1\ A_f]\ /\ (A_f * H)$$

where:

A_f is the floor area in m^2
n_b = number of bedrooms
H is the ceiling height in m.

The third term in the square brackets, ($0.1\ A_f$) is an infiltration credit the standard uses to account for an assumed level of infiltration air entering the building that contributes to meeting the overall ventilation requirement.

The next entry is the mechanical ventilation requirement, based on the U.S. Department of Housing and Urbana Development (HUD) Manufactured Housing Construction and Safety Standards (HUD 1994). The HUD outdoor air ventilation requirement of 0.018 L/ s•m^2, which is based only on floor area, and hence, there is only a single entry, assuming a ceiling height of 2.4 m.

The next three entries are for envelope infiltration only for three different cases of airtightness, and three cases of weather conditions. These values are followed by a very speculative set of values for ventilation via open windows.

Table B2. Single-family home air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.2 requirements				
150 m^2, 2 bedrooms	0.32			
200 m^2, 4 bedrooms	0.35			
300 m^2, 6 bedrooms	0.34			
HUD manufactured house requirements	0.26			
Infiltration Only				
Very tight building		0.1	0.25	0.6
Average tightness		0.25	0.6	1.0
Very leaky		0.5	0.9	1.5
Open Windows Only		1	3	5
Mechanical ventilation (Standard 62.2) combined with infiltration				
Very tight building		0.25	0.4	0.7
Average tightness		0.5	0.7	1.1
Very leaky		0.6	1.0	1.6
Mechanical ventilation (HUD) combined with infiltration				
Very tight building		0.35	0.4	0.75
Average tightness		0.4	0.8	1.2
Very leaky		0.7	1.0	1.7
Mechanical (62.2) combined with open windows		1	3	5
Mechanical (HUD) combined with open windows		1	3	5
NIST U.S. homes analysis				
All data – median	0.45			
Built before 1940 – median	0.60			
Built between 1941 and 1969 – median	0.55			
Built between 1970 and 1989 – median	0.35			
Built after 1990 – median	0.25			

Pandian U.S. homes database				
All data – median	0.50			

Based on measured or design values, +/- 25%

Based on limited measured or design values, +/- 50%

Very speculative, at least +/- 100%

Additional values are included for mechanical ventilation in combination with envelope infiltration for three levels of building tightness and three levels of weather. These values are presented first with the mechanical ventilation rate based on Standard 62.2 and then with the rate derived from the HUD standard. In the case of the Standard 62.2 combined mechanical and infiltration values, the “infiltration credit” is replaced with an infiltration rate that depends on building tightness and weather conditions. This adjustment is more realistic than a single value, but still oversimplifies reality. Two values are also included for the two mechanical ventilation rates in combination with open windows.

The last two sections of Table B2 present the results for two key studies of residential ventilation rates.

The first is a based on a collection of about 200 residences defined to represent 80% of the U.S. housing stock (Persily, Musser, and Leber 2006). This set of dwellings was defined based on an analysis of national housing surveys and subsequently used to develop a national frequency distribution of building ventilation rates under infiltration-only conditions (Persily and Musser 2007). Median values are presented for all the single-family homes in the analysis and for those homes broken down by year of construction. Note that these median values are much lower than many of the estimates earlier in the table, particularly those corresponding to more severe weather. However, given the relative infrequency of severe weather, those high rates do not occur very often and therefore do not impact the median rate very significantly.

The final entry in Table B2 is the median air change rate from a database of measured air change rates in almost 300 homes located throughout the U.S. (Pandian et al. 1998). Note that the homes considered in this database are not statistically representative of the U.S. housing stock and the measurements were made under weather conditions that do not fully characterize the climatic variations over a year.

Schools

There have been very few ventilation measurements in schools, certainly not enough to support a representative value being put forward for general use. In addition, the great variety of building configurations and system types makes any such generalization even more difficult.

Table B3 presents air change rates based primarily on the design requirements in ASHRAE Standard 62.1, with some speculative estimates of the impacts of infiltration and natural ventilation through open windows. This table covers elementary classrooms, lecture classrooms and child care centers separately, with the design rates based on the following three formulas;

$$\text{Elementary classrooms: Air change rate} = 0.036\,[5\,D + 60]\,/H$$

$$\text{Lecture classrooms: Air change rate} = 0.036\,[3.8\,D + 30]\,/H$$

$$\text{Child care centers: Air change rate} = 0.036\,[5\,D + 90]\,/H$$

where:

D = number of occupants per 100 m^2 of floor area
H = ceiling height in m.

Table B3. Educational building air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
ELEMENTARY CLASSROOM				
Mechanical Ventilation				
Standard 62.1 rate no infiltration	3.2			
Standard 62.1, under ventilation	1.6			
Standard 62.1, over ventilation	4.8			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		3.2	3.4	3.6
Average tightness		3.4	3.6	4.0
Very leaky		3.5	4.0	4.5
Mechanical combined with open windows		4	5	6

LECTURE CLASSROOM				
Mechanical Ventilation				
Standard 62.1 rate no infiltration	2.8			
Standard 62.1, under ventilation	1.4			
Standard 62.1, over ventilation	4.2			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		2.8	3.0	3.2
Average tightness		3.0	3.2	3.6
Very leaky		3.2	3.6	4.0
Mechanical combined with open windows		3.5	4.5	5.5
CHILD CARE CENTER				
Mechanical Ventilation				
Standard 62.1 rate no infiltration	4.2			
Standard 62.1, under ventilation	2.1			
Standard 62.1, over ventilation	6.3			
	Weather independent	Weather		Weather independent
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		4.2	4.3	4.5
Average tightness		4.3	4.5	5.0
Very leaky		4.5	5	5.4
Mechanical combined with open windows		5	6	7

Based on measured or design values, +/- 25%

Based on limited measured or design values, +/- 50%

Very speculative, at least +/- 100%

Barracks and Multi-Family Residential

Table B4 presents the air change rate values for barracks buildings. The first entry under mechanical ventilation with no infiltration is based on the requirements in ASHRAE Standard 62.1 of 2.5 L/s per person plus 0.30 L/s per m^2 of floor area, assuming an occupant density of 10 people per 100 m^2 of floor area and a ceiling height of 2.4 m (7.9 ft). Other occupant densities and ceiling heights will correspond to different air change rates per the following formula:

$$\text{Air change rate} = 0.036\ [2.5\ D + 30]\ /H$$

where:

D = number of occupants per 100 m^2 of floor area
H = ceiling height in m.

The values in Table B4 fall into three categories: mechanical ventilation, infiltration only, and open window, similar to those used in the previous tables. There is not a body of ventilation rate measurements in barracks to use in supporting these values, therefore all but the values based on Standard 62.1 are presented as very speculative.

Table B4. Barracks building air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	0.8			
Standard 62.1, under ventilation	0.4			
Standard 62.1, over ventilation	1.2			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		0.8	1.0	1.2
Average tightness		1.0	1.2	1.5
Very leaky		1.2	1.5	2.0
Mechanical combined with open windows		1.5	2.5	3.5

Based on measured or design values, +/- 25%

Very speculative, at least +/- 100%

Table B5 presents the air change rate values for multi-family residential buildings. The first entry under mechanical ventilation with no infiltration is based on the requirements in ASHRAE Standard 62.1 of 2.5 L/s per person plus 0.30 L/s per m^2 of floor area for a dwelling unit in a multi-family residential building. This entry is based on an assumed occupant density of 2 people per 100 m^2 of floor area and a ceiling height of 2.4 m (7.9 ft). Other occupant densities and ceiling heights will correspond to different air change rates per the following formula:

$$\text{Air change rate} = 0.036\ [2.5\ D + 30]\ /H$$

where:

D = number of occupants per 100 m^2 of floor area
H = ceiling height in m.

Like the other tables presented here, Table B5 includes mechanical ventilation, infiltration only and open windows. There is not an adequate body of ventilation measurements in multi-family residential buildings to use in supporting the values in this table, therefore all but the values based on Standard 62.1 are presented as very speculative.

Table B5. Multi-family residential building air change rates

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	0.5			
Standard 62.1, under ventilation	0.25			
Standard 62.1, over ventilation	0.75			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		0.5	0.7	0.9

Average tightness		0.7	0.9	1.2
Very leaky		0.9	1.2	1.5
Mechanical combined with open windows		1.3	2.3	3.3

Based on measured or design values, +/- 25%

Very speculative, at least +/- 100%

While the ventilation requirement in ASHRAE Standard 62.1 for multi-family buildings is for an individual dwelling unit, the values in Table B5 are presented as whole building values. It should be noted that individual units in a multi-family building may be characterized by very different ventilation rates than the whole building value. For example, under heating conditions, units located on the lower floors of a high-rise building are going to have much higher air change rates than those located on the upper floors, due to the stack effect.

Retail, Restaurants and Theaters

Tables B6B8 present the air change rate values for retail buildings, restaurants and theatres.

The first entry in each table, under mechanical ventilation with no infiltration, is based on the requirements in ASHRAE Standard 62.1. These requirements are 3.8 L/s per person in all three space types, plus 0.60 L/s per m^2 of floor area in retail spaces, 0.90 L/s per m^2 in restaurants and 0.30 L/s per m^2 in theaters. The default occupant density in the standard is 15 people per 100 m^2 of floor area in retail spaces, 70 people per 100 m^2 in restaurants, and 100 people per 100 m^2 in theaters. The assumed ceiling height is 2.4 m (7.9 ft) in retail and restaurants and 3.65 m (12.0 ft) in theaters. Other occupant densities and ceiling heights correspond to different air change rates per the following formulas:

$$\text{Retail: Air change rate} = 0.036\ [3.8\ D + 60]\ /H$$

$$\text{Restaurants: Air change rate} = 0.036\ [3.8\ D + 90]\ /H$$

$$\text{Theaters: Air change rate} = 0.036\ [3.8\ D + 30]\ /H$$

where:

D = number of occupants per 100 m^2 of floor area

H = the ceiling height in m.

The values in Tables B6B8 fall into three categories: mechanical ventilation, infiltration only, and open windows. There is not a body of ventilation rate measurements in retail spaces, restaurants, or theaters to use in supporting the values in these tables. Therefore, all but the values based on Standard 62.1 are presented as very speculative.

Table B6. Retail air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	1.8			
Standard 62.1, under ventilation	0.9			
Standard 62.1, over ventilation	2.7			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		1.8	2	2.2
Average tightness		2	2.2	2.5
Very leaky		2.2	2.5	3
Mechanical combined with open windows		2.5	3.5	4.5

Based on measured or design values, ± 25%

Very speculative, at least ± 100%

Table B7Restaurant air change rates

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	5			
Standard 62.1, under ventilation	2.5			
Standard 62.1, over ventilation	10			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3

Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		5	5.2	5.4
Average tightness		5.2	5.4	5.7
Very leaky		5.4	5.7	6
Mechanical combined with open windows		5.8	6.8	7.8

Based on measured or design values, ± 25%

Very speculative, at least ± 100%

Table B8. Theater air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	4			
Standard 62.1, under ventilation	2			
Standard 62.1, over ventilation	6			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		4	4.2	4.4
Average tightness		4.2	4.4	4.7
Very leaky		4.4	4.7	5
Mechanical combined with open windows		4.6	5.6	6.6

Based on measured or design values, ± 25%

Very speculative, at least ± 100%

Hospitals, Gymnasiums, Warehouses and Commissaries

Tables B9B12 present the air change rate values for hospitals, gymnasiums, warehouses, and commissaries. The first entry in each table, under mechanical ventilation with no infiltration, is based on the requirements in ASHRAE Standard 62.1. These requirements are 8 L/s to 15 L/s per person in hospitals, depending on the type of room, with a default occupant density of 10 people to 20 people per 100 m^2, again depending on the type of room. The ventilation requirements in gymnasiums and warehouses are 1.5 L/s per m^2 of floor area and 0.30 L/s per m^2 respectively, with no dependence on the number of occupants. The air change rates for commissaries are based on the ventilation requirements for supermarkets in the standard, which are 3.8 L/s per person and 0.30 L/s per m^2 of floor area, and a default occupant of 8 people per 100 m^2. The assumed ceiling height is 2.4 m (7.9 ft) in hospital patient and treatment rooms and 3.65 m (12.0 ft) in operating rooms and the other three building types.

Other occupant densities and ceiling heights will correspond to different air change rates per the following formulas:

Hospitals: Air change rate = 6.1 D /H
Gymnasiums: Air change rate = 5.4 /H
Warehouses: Air change rate = 1.1 /H
Commissaries: Air change rate = 0.036 [3.8 D + 30] /H

where:

D = number of occupants per 100 m^2 of floor area
H = ceiling height in m

The equation for hospitals is based on a generalized space type corresponding to 10 L/s per person and an occupant density of 17 per 100 m^2 of floor area.

The values in Tables B9B 12 fall into three categories: mechanical ventilation, infiltration only, and open windows only. There is not a body of ventilation rate measurements in hospitals, gymnasiums or warehouses to use in supporting the values in these tables, therefore all but the values based on Standard 62.1 are presented as very speculative.

Table B9. Hospital air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	2.5			
Standard 62.1, under ventilation	1.3			
Standard 62.1, over ventilation	3.7			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3

	Weather independent	Weather	Weather independent	Weather
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		2.5	2.7	2.9
Average tightness		2.7	2.9	3.3
Very leaky		2.9	3.3	3.6
Mechanical combined with open windows		3	4	5

Based on measured or design values, ± 25%

Very speculative, at least ± 100%

Table B10. Gymnasium air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	1.5			
Standard 62.1, under ventilation	0.8			
Standard 62.1, over ventilation	2.3			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		1.5	1.7	1.9
Average tightness		1.7	1.9	2.3
Very leaky		1.9	2.3	2.6
Mechanical combined with open windows		2.2	3.2	4.2

Based on measured or design values, ± 25%

Very speculative, at least ± 100%

Table B11. Warehouse air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	0.3			
Standard 62.1, under ventilation	0.2			
Standard 62.1, over ventilation	0.5			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		0.3	0.45	0.6
Average tightness		0.45	0.6	1.0
Very leaky		0.6	1.0	1.5
Mechanical combined with open windows		1	2	3

Based on measured or design values, ± 25%

Very speculative, at least ± 100%

Table B12.Commissary air change rates.

	Weather independent	Weather		
		Calm	Moderate	Severe
Mechanical Ventilation				
Standard 62.1 rate no infiltration	0.9			
Standard 62.1, under ventilation	0.5			
Standard 62.1, over ventilation	1.4			
Infiltration Only				
Very tight building		0.1	0.25	0.5
Average tightness		0.25	0.5	1.0
Very leaky		0.5	1	1.5
Open Windows Only		1	2	3
Mechanical ventilation (Standard 62.1) combined with infiltration				
Very tight building		0.9	1.1	1.3
Average tightness		1.1	1.3	1.5
Very leaky		1.3	1.5	1.8
Mechanical combined with open windows		1	2	3

Based on measured or design values, ± 25%

Very speculative, at least ± 100%

Summary

The building air change rates presented in this report are based on a combination of the ventilation requirements in ASHRAE Standard 62.1-2007, the very limited number of measurements conducted in the field, and a significant amount of engineering judgment. Any use of these rates must be fully informed by their limitations, particularly their lack of specificity to any particular building, system design, operating conditions or weather conditions, and by their limited basis in actual measurement.

For many of the building types or conditions (e.g. open windows), few, if any, air change rate measurements even exist. Nevertheless, these rates may prove useful for certain types of analysis where there is no need to differentiate between building types, system operation, and weather conditions. The gaps noted in measured ventilation rates also highlight the need for more field studies and simplified calculation tools to determine building ventilation rates, particularly in buildings other than offices and residences.

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14. ABSTRACT

The release of an airborne hazardous substance nearby or within a military facility can threaten the life or safety of government personnel and the general public. Vulnerability assessments using simulants and sensors are expensive and may interfere with normal facility operations. Simulation modeling technology offers a possible method for understanding how airborne hazardous substances may circulate inside and around any specific facility affected by an attack or accidental release. Improved understanding of airborne threats could shorten emergency response time and minimize casualties at the site. A computerized simulation tool called CBRSim, developed under an earlier U.S. Army research program, provides an environment for creating and testing models of release patterns for airborne weaponized agents within or nearby a targeted facility. This report describes the CBRSim tool and explains how it could be used to assess chemical, biological, and radiological (CBR) weapons effects for specific facilities. The discussion includes the results of case studies and simulations run during a workshop for military installation stakeholders presented at Fort Carson, CO.

Demonstration results indicate that CBRSim is not sufficiently developed to provide reliable situation data in real time, but offers benefits as a training and education aid for facility managers and first responders.

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